THE PRINCIPLES OF ELECTROTHERAPY

AND THEIR PRACTICAL APPLICATION

W. J. TURRELL

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Siquid novisti rectius istis,
candidus imperti: si non, his utere mecum.
Horace, *Ep.* i 6. 67–8.

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PREFACE

THIS book is the outcome of an attempt to explain the therapeutic action of electricity upon rational grounds and upon physiological principles.

In Part I current electricity is discussed. The therapeutic action of static electricity is here considered, because it is mainly the currents derived from the static machine, and not the static charge itself, which possess therapeutic action. The static machine serves to generate a static charge, which, when sufficient voltage has been attained, discharges as a current of very low intensity, but of very high potential, and so affords methods of therapy unattainable by other means.

The necessity of clearly distinguishing between the polar and inter-polar action of the constant current is pointed out. The action of interrupted currents of low frequency is shown to be due to the relatively high velocity of the hydrogen ion compared to the velocities of the other ions in the tissues.

The steps by which D'Arsonval was led to the discovery of high-frequency currents are described, with extracts from D'Arsonval's original paper. The action both of high-frequency currents of tension and of quantity are fully discussed.

The second part of this book deals with the fascinating and difficult task of explaining the therapeutic action of radiant energy. Tracing this method of treatment from its general principles we are led step by step to formulate a new hypothesis, or, perhaps, to develop an existing theory of the therapeutic action of the radiation from an X-ray tube or radium. We first of all note the fundamental identity of the mode of action of ultra-violet radiation with that of the radiation from X-rays and

radium. We realize that radiation. like light, only acts when it is absorbed, and we next find that Kohler has shown that the nuclei of the cells in the gill plate of the salamander are ' particularly opaque to light of the wave length of the ultra-violet ' (Bayliss). Tracing this subject farther we learn from Dr. Regaud that it is the chromatin of the nuclei, at the time of their division, which is the most radio-sensitive component of the human tissues, and consequently is the first to be destroyed by the radiation of X-rays. We are, then, met with the difficulty that the immediate destruction of the cells does not account for the latent period which precedes the characteristic reactions of both ultra-violet radiation and X-rays. To account for this latent period, we suggest the setting free of some toxin resulting from the splitting up of the chromatin. Passing on later to discuss the very important question of the action of X-rays on the blood, we find that the presence of such a destructive toxin or ferment, a leucolysin, has been clearly demonstrated by Curshmann and Gaupp, as occurring after the exposure of a leukæmic patient to X-rays. We are thus enabled not only to complete the evidence in support of our theory, but also to suggest an explanation of the recognized diminution in the efficiency of repeated radiation by X-rays in the treatment of leukæmia, on the possible and rational ground that, as the outcome of the action of the toxin, antibodies are developed which render the white corpuscles less radio-sensitive.

The recent work of the Erlangen gynæcologists, Drs. Seitz and Wintz, appears likely to revolutionize to a very large extent our views on radiotherapy. At first sight we are apt, impressed by the great increase in the power of their apparatus and the prolonged exposure which they administer, to lose sight of the careful and far-reaching experiments upon which their methods are based.

It is, however, from the latter, and especially from their systematic tabulation of the varying lethal doses required

to destroy different types of cells that the most lasting and valuable results are likely to spring. A single instance will suffice to illustrate this point : if 40 per cent. of the unit skin dose, as Drs. Seitz and Wintz state, has the effect of stimulating rather than destroying cancer cells, then the present practice of employing prophylactic radiation, before operation, and also post-operative radiation, should be immediately discontinued. For the doses generally given in this country for these purposes do not usually exceed this 40 per cent., and consequently their application is far more likely to prove harmful than beneficial : moreover, the necessary lethal dose required to destroy cancer cells is far too drastic and provokes too grave constitutional disturbances to be used for prophylactic purposes.

It is not possible within the limits of this book to give more than a broad outline of the work of the Erlangen technique, and it is far too early to pronounce definitely upon its merits ; but as it is certain that this method of treatment will exercise a most powerful influence on the future of radiotherapy, an attempt has been made to deal briefly with its essential points.

The third part is concerned with electro-diagnosis. The chief portion, dealing with the electrical diagnosis of peripheral nerve lesions, has already appeared in the *American Journal of Electrotherapeutics*. A chapter on the electro-diagnosis of certain diseases has been added.

The fourth part explains the action of electrotherapy in some of the diseased conditions for which it is applied, and indications are given of the type of case suitable for electrical treatment. To this part some practical hints on treatment are added.

In the compilation of this book I have drawn very largely upon the writings of French electrotherapists—in no other way would it be possible to deal adequately with this subject. No student of the history of electrotherapy can fail to recognize the fact that this form of treatment

was first placed upon a scientific basis as the result of the work of French scientists. Imbued, perhaps, with the pride of antiquity, we trace the pedigree of this speciality back to the writings of the ancient Greeks: yet, nevertheless, every electrotherapist, whatever his nationality may be, is proud to claim as the Founder and the Father of Modern Electrotherapy that great scientist, Duchenne, of Boulogne, whom a French speaker so well described as ' the man who has played a preponderating part in the researches and discoveries, upon which the edifice of neuro-pathology has been erected '. These researches were based upon, and these discoveries resulted from—as Duchenne himself states—' a method of electrization, which surpassed his expectation in yielding scientific and practical results of the highest importance '.

I am especially indebted to the writings of Professor Bergonié, Drs. Miramond Laroquette, Nogier, Bordier, Béclère, Larat, Regaud, Max Roques, and MM. David and Desplats.

Due acknowledgement must also be made of the assistance in reference to the static machine which I have received from the writings of Dr. Benham Snow, of New York, who has done so much to develop the use of this instrument; and in connexion with the same subject I should like to record my indebtedness to Dr. Howard Humphris, to whose kindness I owed my first introduction to this useful machine, and also many valuable hints in regard to the methods of employing the currents derived from it. In dealing with radiant energy I have been greatly assisted by Professor Merton's kind advice and helpful criticism. Like other radiotherapists in this country I was indebted for my earliest information of the Wintz method to Dr. Reginald Morton, whose paper, published in the *Proceedings of the Royal Society of Medicine*, I have so largely drawn upon when dealing with that intensive method of radiotherapy. I have also, in discussing this important subject, availed myself of some

extracts from the comprehensive book of Drs. Seitz and Wintz.

To Dr. E. D. Adrian, of Cambridge, whose experimental work has done so much to elucidate the principles upon which electro-diagnosis is based, I owe my thanks for his kind permission to utilize the illuminating diagrams of a case of recovering facial paralysis. Finally, I must not omit to acknowledge the great assistance I have derived from repeated and careful perusal of that mine of physiological information, Professor Bayliss's *Principles of General Physiology*.

In conclusion, I would venture to express the sincere hope that this small book may in some slight degree help to harness to the service of the healing art, the most powerful, the most easily regulated, and the most fundamental force in nature.

W. J. T.

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PART I
THE THERAPEUTIC ACTION OF CURRENT ELECTRICITY

CHAPTER I
THE THERAPEUTIC ACTION OF THE CONSTANT CURRENT

The therapeutic effects of the galvanic current vary with its method of application. If the current is interrupted, reversed, or suddenly varied in intensity, muscular contractions are excited and influence its action. When the current is continuous and maintains a permanent value between make and break (the constant current), its action at the electrodes is not of the same nature as in the interpolar path through the tissues: for at the electrodes electrolytic effects are manifested, and these result in tissue destruction, both by electrical decomposition and by the chemical action of the electrolytic products.

It is in the interpolar path through the tissues of the body that the galvanic current exercises its most important action, and produces therapeutic effects which are more generally useful than any other form of electrical treatment. It is very difficult, however, to explain clearly and definitely the nature of this action. The explanation usually given, that the beneficial effects are due to the 'ionic interchange' which takes place in the tissues, does little more than beg the question: for what is this ionic interchange that takes place, and how does

it affect the nutrition and metabolism of the tissue cells? The fact that thermal changes take place in the interpolar path admits of no question, for they can be readily demonstrated during the course of a galvanic treatment. But to what is this increase in temperature due, and what are its effects? Is it merely due to the resistance offered to the passage of the current in accordance with Joule's Law? Or is it in part due to chemical action, or to increased cellular activity due to 'ionic interchange' in the tissues?

Again, take the case of a knee joint with much fibrous thickening, the result of chronic rheumatism. The skin of such a joint is glossy, denuded of hair, and is in a generally atrophic condition. After a prolonged course for some months of intensive galvanism, the fibrous thickening is much reduced, the pain is lessened or entirely removed, the mobility of the joint is increased, the skin has lost its atrophic appearance, and the growth of hair on the part is probably in excess of the normal. To what are we to attribute these changes? Is the disappearance of the fibrous tissue due solely to an increased blood supply consequent on the increased heat produced in the part by the passage of the current, or has the current some more direct action, such as by electrolysis, namely, the splitting up of the newly-formed fibrous tissue, in a manner somewhat analogous to the destructive effects of X-rays and ultra-violet radiation by the ionization of newly-formed fibrous tissue cells? Can the improvement be in any way attributed to the local action of drugs conveyed deeply into the tissues by the electrical current, that is to say, by the action of the so-called 'ionic' medication'?

Further, are the nutritional effects on the skin due to the direct, or to the reflex effects of its repeated stimulation? That is to say, are these effects the result of direct stimulation of the skin by the electrolytic formation of hydrochloric acid at the anode, and caustic soda at the kathode? Or are they due to the reflex action of such

stimulation resulting, not only in an increased blood supply to the part stimulated, but in a hyperæmia shared by the whole limb? Finally, does the passage of an electrical current through the body modify or influence in any degree the normal or disordered electrical processes of the organism?

These questions open a very wide field for discussion; it is probable that the action of the galvanic current on living tissues is a very complex one, and is not due to any

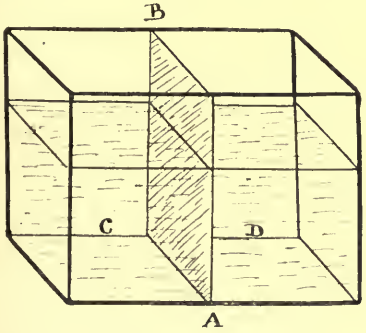

FIG. 1. Rectangular vessel divided by membranous partition to illustrate osmosis and formation of ions.

single one of the above-suggested causes. To what extent each of them may share in producing the therapeutic results can be best ascertained by a brief *résumé* of the physical action of the galvanic current.

If we take a rectangular vessel A, divided into two compartments C and D by a membranous partition B, and fill these two compartments with a solution of uniform concentration and character, the osmotic pressure (namely, the force exciting diffusion of the fluids through the membrane) is equal; or, as it is termed, isotonic. But if the molecular concentration of the solution in D is greater than that of the solution in C, the osmotic pressure of the solution in D is said to be hyper-tonic, and that in C hypo-tonic. In other words, the osmotic pressure of a solution is directly proportional to its concentration in

unit volume. Certain substances, such as the salts, when dissolved in water, exercise an osmotic pressure greater than can be explained by their molecular concentration. Therefore it is suggested that the molecules have been divided into smaller particles or sub-molecules. Substances which give in watery solution this increased osmotic pressure are found to conduct the electrical current, and their solutions are at the two poles split up or decomposed by the passage of the current. These substances include the acids, bases, and salts. They are termed electrolytes, or ionogens, and the smaller substances into which they are split up are called ' ions ' or travellers, a name first conferred upon them by Faraday, and derived from the Greek word ἴον.

Substances such as alcohol, sugar, chloroform, whose solutions give a normal osmotic pressure and do not conduct the electrical current, are termed ' non-electrolytes '.

When a salt, such as sodium chloride, is dissolved in water, it is split up or dissociated, *without the application of any external force*, into a positively charged sodium ion and a negatively charged chlorine ion On the application of an electrical current, the positively charged sodium ion is attracted towards, and carries its electrical charge *down* to, the negative pole, and is hence called a *kation*. The negatively charged chlorine ion is attracted by the positive pole, and hence carries its charge *up* to the positive pole, and is called an *anion*. The current is hence a double one.

This process of the dissociation of salts or other ' ionogens ' into ions is termed ' ionization '. This term ' ionization ' is used in electrotherapy in a very confusing and faulty manner ; it is frequently employed to designate a form of treatment which has no relation whatever to the correct application of the term. Let us clearly understand what is correctly implied by the term.

The term ionization, when applied to a liquid, implies the dissociation of a substance into ions without the application of any external force, as is the case when

a salt is dissolved in water. The term ionization, when applied to gases, implies the splitting up of the molecules of the gas or air into ions, by the application of an external force, such as X-rays or ultra-violet light : the gas, or air, is, by means of this external force, rendered a conductor of electricity in the same way as water is so converted by the dissociation of a salt into ions, the action of the X-rays on the air or gas resulting in the formation of both positive and negative ions.

The kations consist of the metals and hydrogen. The anions include iodine, chlorine, the bases, and acid radicles, such as hydroxyl, OH.

It is the ions which convey the current through the electrolyte ; the anions carrying a negative charge to the positive pole, and the kations carrying a positive charge to the negative pole. In the words of Leduc, the movement of the ions in the electrolyte ' est le courant électrique lui-même '. The dissociated molecules, whilst they are in the ionic state, do not exhibit their former chemical affinities.

The electrical charge of the ion, according to Nernst, momentarily replaces the affinity of the atom. When the atom or radicle has lost this charge, its affinity reappears (Nogier).[1]

Apart from variations due to temperature and E.M.F., ions have a specific rate of movement according to their nature. The resistance, and conversely the conductivity of electrolytic solutions is determined by the number of ions they contain, and by the rate of movement of those ions.

The velocity of the different ions is partly in relation to their atomic weight, and is partly due to their hydration, namely, the number of molecules of water that they attract to themselves (2).

[1] It would, perhaps, be more explicit to say that the chemical affinity of an atom in an ionic state is temporarily inhibited by the electrostatic attraction of a neighbouring and oppositely charged ion.—W. J. T.

The conductivity of the following ions is taken from the tables of Kohlrausch and Holborn :

Kations : Potassium 65·3. Sodium 44·4. Lithium 35·5. Hydrogen 318.

Anions : Chlorine 65·9. Iodine 66·7. $1/2SO_4$ 69·7. Hydroxyl 174.

It will be noticed that among the kations the hydrogen ion, and among the anions the hydroxyl ion, is by far the fastest. It will be also seen that the lithium ion, which has an atomic weight of only seven, travels at little more than half the rate of the potassium ion, which has an atomic weight of thirty-nine. The low velocity of the lithium ion is due to its hydration, namely, the large number of molecules of water which are attached to it.

These ions, which are present in millions in electrolytic solutions, have, on account of the resistance they encounter and their frequent collision with the undissociated molecules in the solution, a very slow rate of travel.

The ionic velocity in an electrolyte varies directly with the E.M.F. The larger the surface of the electrodes, the greater the number of ions which will be included in the interpolar path, and hence the greater the amount of current which will be carried with a constant E.M.F. In an electrolyte of one square centimetre cross-section, with a fall of potential (Potential Gradient) of one volt per centimetre length, the hydrogen ion has been found to move only at the rate of 0·0033 cm. per second, and the potassium ion at 0·00067 cm. per second.

According to Kohlrausch's *Law of the Independent Migration of Ions*, the conductivity of an electrolyte, containing a variety of ions with varying velocities, is the sum of the velocities of the individual ions.

One of the most striking, and, from the electrotherapeutic standpoint, one of the most important characteristics of the passage of a galvanic current through an electrolyte, is the absence of any chemical action in the general bulk of the electrolyte as the result of the passage of the ions ; it is only when the ions reach the electrodes

and there surrender their electrical charges that they regain their chemical affinities and exercise their specific reactions. The following experiment of Hittorf's illustrates this: Take a rectangular glass jar, divided by means of two porous plates into three divisions. Having filled each of the compartments with a solution of copper sulphate, place in each of the outer divisions a copper electrode, and connect one of these with the positive, and

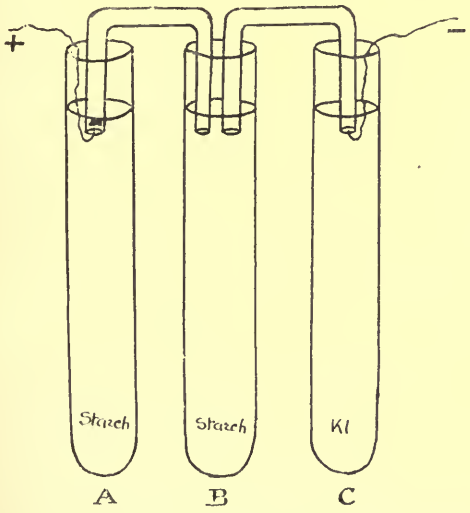

FIG. 2. Author's experiment to illustrate transport of ions.

the other with the negative terminal of an electrical supply. After a strong current of several amperes has passed for some minutes, the solution in the anodal compartment will be found to have become stronger, in the cathodal compartment the solution will be weaker, and in the centre compartment the solution will be found to be unaltered in strength. The same result may perhaps be more readily shown by the following simple experiment of the author (Fig. 2). Take three glass test-tubes, A, B, and C. Fill C with a 2 per cent. solution of potassium iodide, and A and B with a weak emulsion of starch.

Connect the tubes A, B, and C with narrow strips of coagulated egg albumen, obtained from the white of a hard-boiled egg. In the tube C place the negative electrode of copper, zinc, or other metal ; and in the tube A place the positive electrode of platinum wire in contact with the strip of albumen submerged in the starch emulsion. Pass a galvanic current of about 5 ma. for about forty-five minutes. The contents of the tubes B and C will then be found to be unaltered, but in immediate contact with the positive electrode there will be found an intense blue discoloration due to the starch iodine reaction.

This experiment therefore shows that the very delicate starch iodine test fails to reveal the presence of any free iodine except in contact with the positive electrode, where the iodine ion, having passed through the tube B without producing any chemical change in its path, loses its negative electrical charge to the positive pole, and regains its chemical affinity as an iodine atom.

The chief value of these experiments and of the somewhat similar experiments of Chatsky, described below, lies in the evidence they afford of the fallacy of the deep ionic medication theory, which is so widely held and taught.

According to this theory it is held that by means of the electrical current it is possible to introduce drugs into the deeper tissues of the body and there obtain the specific action of the medicament.

The first of Chatsky's experiments is so simple that every electrotherapist should perform it for his own instruction.

Fig. 3. A hole is scooped in a potato at A, and filled with a 1 per cent. solution of potassium iodide; platinum wire electrodes are inserted into the potato, the positive at B and the negative at C. A continuous current of about 3 ma. is passed for about thirty minutes. Then, on bisecting the potato longitudinally through the points of insertion of the electrodes, a short pencil-like rod, clearly

and sharply defined, of an intense blue colour, due to the action of the liberated iodine on the starch of the potato, will be seen starting from the positive electrode and directed towards the hole A. After a short time the pencil-like rod, owing to diffusion, merges into a wider and less sharply defined area. Between the upper extremity of

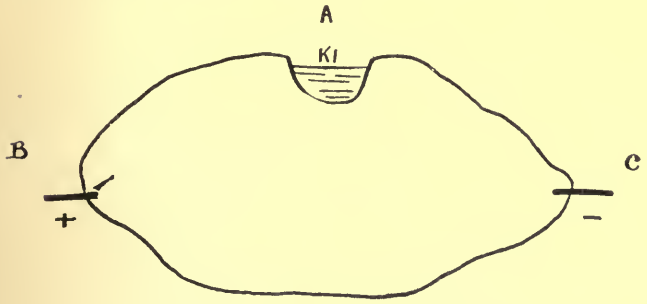

FIG 3. Chatsky's first experiment.

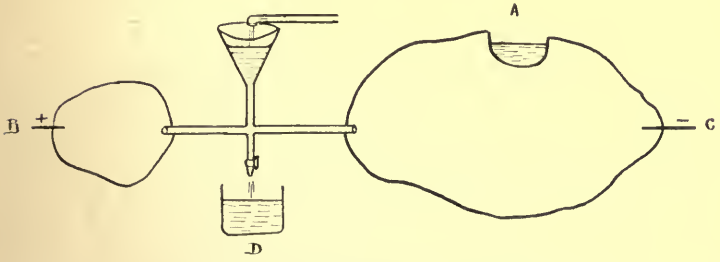

FIG. 4. Chatsky's second experiment.

this rod and the hole A, no colorization and no change in the substance of the potato can be detected. Incidentally two other points may be noted from this experiment, (1) the diffusion of the lines of force, and (2) that fresh ions may start from any part of the interpolar path and share in the conveyance of the current.

In Chatsky's second experiment, two potatoes are connected by a cross-shaped glass tube, through which a continuous stream of sodium chloride solution flows in

a transverse direction to the current; see Fig 4. A solution of potassium iodide is inserted in the hole A, and an electrical current passed, as in the first experiment; but in this case no blue coloration appears at the positive pole, but a slight blue colour, due to the starch iodine reaction, can be detected in the vessel B.

This experiment is in full accord with the phenomenon attending the so-called ionization with strychnine in Leduc's experiments with rabbits.

Fig. 5. In this experiment, two rabbits, A and B, are taken, and, their sides having been shaved, a pad soaked in a 2 per cent. solution of strychnine is applied to one

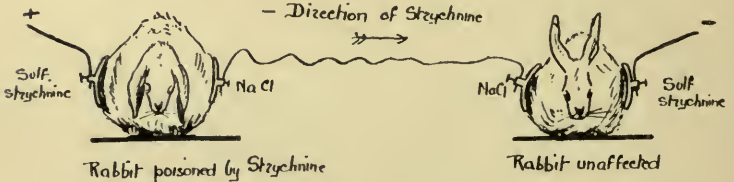

FIG. 5. Leduc's experiment.

shaven side of each rabbit, and to the other side a pad soaked in a 2 per cent. solution of sodium chloride is applied. The rabbits are connected up in series with a galvanic supply, and the electrodes are so arranged that the strychnine pad is under the positive pole in the rabbit A and under the negative pole in rabbit B. A current of 50 to 100 ma. is applied for some minutes, with the result that the rabbit A dies in convulsions, whilst the rabbit B is unaffected; unless, perchance, the current is reversed, when rabbit A survives and rabbit B succumbs.

The sequence of events is quite clear in this case; the strychnine, being an alkaloid, is a kation, and serves to conduct the current through the badly-conducting skin under the positive pole. Having been carried to the subcutaneous tissues by the strychnine ions, the current is then carried by the hydrogen and other ions in the tissues, and the strychnine atoms are swept away in the

blood stream (in the same way as the iodine atoms are carried to the vessel by the transverse sodium chloride stream in Chatsky's second experiment) and carried in the course of the circulation to the spinal cord, where, released of their electrical charges, the strychnine atoms exercise their lethal action.

In a similar manner the presence of iodine and other drugs in the urine may be accounted for when introduced to the subcutaneous tissues during attempts at ionic medication.

It is not necessary, however, to rely upon these experiments, for the most direct proof against the practicability of deep ionic medication is to be found in the failure to detect the presence of the drug deeper than the superficial layers of the skin. The experiments of Tuffier and Maute failed to detect the presence of salicylate beyond the superficial layers of the skin.

Dr. Levick, Electrotherapist to the Shepherd's Bush Orthopædic Hospital, has very kindly sent me the following particulars of a most careful and instructive experiment which he performed confirming the work of the French investigators :

'A patient suffering from sciatic nerve degeneration, complicated by ischaemia of the foot, was about to undergo amputation of his leg. He allowed me to perform the following experiment. Two ionization pads, each consisting of sixteen layers of lint, were bandaged to his foot, one on the dorsum. the other on the sole. The pad applied to the dorsum was soaked with a 2 per cent. solution of sodium salicylate. The pad applied to the sole was soaked with tap water. The usual precautions were taken to prevent short circuiting between the two pads. Metal gauze electrodes connected the pads with the galvanic current regulated by a shunt resistance. The pad containing the sodium salicylate was made the negative, and a current varying from 60 to 70 ma. was run through for three-quarters of an hour. An hour and

a half later the patient was taken to the operating theatre and his leg was amputated.

'Dr. Mellanby, of St. Thomas's Hospital, had kindly consented to carry out the tests for me. I thought that for the experiment to be of any real value, a pharmacist of unquestionable authority must do these. I sent the amputated limb straight to him. He made extracts of the tissues of the foot from several places at varying depths, from the superficial fascia down to the tarsal joints. He assured me that he had employed very delicate tests which would have shown the slightest presence of salicylic acid, but that they were absolutely negative. The significance of this experiment was enhanced by the fact that the circulation was extremely sluggish, and had any appreciable quantity of salicylic acid been conveyed into the tissues there was less chance than usual of its being carried away.'

Even if such drugs as salicylic acid and lithium were capable of being conveyed to the deeper tissues by the electrical current, there is no reason to suppose that they would necessarily exercise any beneficial effect in those regions. On the contrary, in general therapy we give such drugs, in large quantities, and in oft-repeated doses, with a view to some neutralizing action on the blood in certain diseases, and no special benefit is alleged to follow from their direct injection to the diseased locality. Again, where a drug, such as cocaine, can be electrically introduced to the sensory nerve endings, its action has been found to be uncertain, and by no means so satisfactory as when injected hypodermically.

The slow rate of movement of the ions is another point which seems to be overlooked by the holders of the ionic medication theory, and yet this fact alone is sufficient to disprove many of the claims made for this theory.

The evidence against the possibility of the local medication of the deeper tissues by drugs, electrically introduced, is so overwhelming that it is extraordinary that this

theory of ionic medication should be so widely held. And yet it is only a case of history repeating itself, for very similar theories were advanced by Privati, in 1747, and by Sir Benjamin Ward Richardson, in 1858. Nevertheless, however fallacious this theory of ionic medication may be, it must be admitted that its revival in the twentieth century has been of the greatest value to the development of electrotherapy. Many persons, both patients and medical men, with little or no knowledge of electricity, but inspired with that marvellous faith which a bottle of medicine, of unknown action and of uncertain composition, invariably imparts, were irresistibly attracted by a theory, according to which, as Priestley says, ' medicines might be made to operate without being taken into the stomach '. Moreover, as the result of this theory, we have learnt the proper manner in which to administer the galvanic current. Instead of, as formerly, administering the current with small electrodes over small areas for a few minutes, we, as the outcome of this theory, now apply the treatment over large areas, with currents of low density and high intensity, for thirty, forty-five minutes, or ' as long as the time of the department will permit ', for periods of weeks or months.

We have seen that the conductivity of an electrolyte depends upon the number of ions it contains, and upon the velocity of those ions. Once within the skin the situation is governed by the relative velocity of the hydrogen kations and the hydroxyl anions to the other ions present in the tissues. So far as I am aware even an approximate calculation of the hydrogen and hydroxyl ions available within the tissues for the transmission of the electrical current cannot be made ; but upon any estimation they must so enormously outnumber those ions introduced from outside, as to render the latter an utterly negligible quantity in considering the transmission of the current through the tissues. This question of the transmission of the current through the tissues is governed by Kirchhoff's

law of branched circuits. Why should we abrogate the established laws of electricity to bolster up this theory of ionic medication ?

Will any upholder of that theory explain why the current travels, as becomes necessary if the theory is correct, by the comparatively high resistance offered by the ions of the drugs introduced, in preference to the path of far lower resistance afforded by the hydrogen and hydroxyl ions present in the tissues in far larger numbers and of far higher velocity ?

The arguments against the theory of ionic medication may be briefly summarized as follows :

1. While a salt is in an ionic state its chemical affinity is temporarily inhibited by its electrical charge, therefore as an ion it can have no therapeutic action.

2. The very low velocity of the ions employed in medical treatments of this character and the very low potential at which they are applied entirely preclude the deep penetration claimed for them during the brief period allotted to an electrical treatment.

3. According to Sir Oliver Lodge, 'at a change of liquid another set of atoms continues the convection, and nothing very particular need be noticed at the junction.'

4. Such drugs as salicylic acid, commonly employed, need to be present in the tissues in considerable quantities in order to exercise their therapeutic effect, and it is difficult to conceive that such drugs in the infinitesimal quantities, which could possibly be introduced by ionic medication, could have any beneficial action.

5. Many workers of extensive experience have failed to detect any difference in their results, provided the current is administered at a similar intensity, and for a similar length of time, whatever salts or drugs are employed to moisten the pads.

6. Very careful experiments conducted both in this country and in France, by experienced electrotherapists

in collaboration with skilled chemists, have failed to detect the presence of the drug, after its attempted introduction by electrical means, deeper than the superficial layers of the skin.

The experiments to prove the electrical introduction of the ferricyanide ions into the knee joint of the monkey should be entirely disregarded, since after the ferricyanide ions had been electrically introduced into the neighbouring superficial layers of the skin, the knee joint of the dead monkey, so treated, was allowed to soak in the reagent for more than twenty-four hours, thus admitting a very simple explanation of the phenomenon obtained, namely, by the diffusion that we should expect to occur under such conditions.

As regards the alleged introduction of radium salts deeply into the tissues, the marvellously delicate tests available for the detection of radium, even when present in inconceivably small quantities, renders the use of these salts very misleading for the purpose of demonstrating by analogy the introduction of other drugs deeply into the tissues in chemically active quantities.

It is true that drugs, electrically introduced in an ionic state into the superficial layers of the skin, may be from thence absorbed into the general circulation, and may then exercise their specific action on the system generally.

In view of the extremely minute quantities which can be so introduced and the complicated technique of the method, there is nothing to recommend its adoption in preference to inunction or oral administration. Take, for instance, cocaine, a drug whose nature readily admits of its electrical introduction to the sphere of its therapeutic action; its effects, when electrically introduced to the subcutaneous nerve endings, have not been found to be by any means so satisfactory or reliable as when it is hypodermically injected.

When these points are rationally and dispassionately considered, it must be admitted that the theory of ionic

medication fails on theoretical, on practical, and on experimental grounds.

The claim put forward by some electrotherapists that the galvanic current exercises an electrolytic action throughout the whole of its interpolar path need not be seriously considered : such a theory is of course entirely opposed to the fact demonstrated many years ago by Faraday, that electrolytic action takes place solely at the electrodes. When at a loss to explain the action of the galvanic current some electrotherapists glibly talk of the ' ionic interchange which takes place within the tissues as the result of the action of the galvanic current ' ; but what the nature of this ' ionic interchange ' is, or how it acts, they do not aettmpt to explain.

The conclusion arrived at then is that the function of the solution of salts, or of other drugs with which the pads are moistened, is to supply the ions necessary for the transmission of the current through the superficial layers of the skin, an area which is normally very deficient in ions. Without the employment of such solutions the electrical resistance of the skin would be so great that a very high voltage would be necessary to force the necessary current through it : burns of the skin would consequently result, and the administration of the treatment would be extremely painful. When the deeper layers of the skin are reached, the fluids in which the tissues are bathed contain innumerable numbers of the relatively fast hydrogen kations and the hydroxyl anions, and hence these serve to carry, at any rate, by far the greater amount of the current.

An attempt is sometimes made to explain the action of the galvanic current by the electrotonus which it excites in the nerves through or along which it passes. It will be remembered that electrotonus is the condition produced in a nerve by the passage of the constant current. If the constant current is applied through the nerve of a nerve-muscle preparation in the same direction

as the natural nerve currents, the excitability of the nerve is increased (katelectrotonus); but if it is applied in a direction contrary to the natural nerve currents, the excitability of the nerve is diminished (anelectrotonus). This is very similar to what occurs with the Watteville currents, katelectrotonus corresponding to the Watteville current in tension, and anelectrotonus to the Watteville current in opposition. Relying on this laboratory experiment it is claimed that the constant current applied with the negative pole at the proximal end of the nerve or limb has a sedative action, and with the poles reversed an exciting or irritating action. No definite conclusions can, however, be drawn from a laboratory experiment in which the whole of a current of a definite and known intensity is passed along an isolated nerve, in regard to the effects arising from the passage of an extremely minute current of unascertainable strength along a nerve of high electrical resistance situated deeply in tissues of very low electrical resistance.

Personally I have never been able to convince myself that I have derived any advantage from such an arrangement of the electrodes, and in any case the benefit resulting from such a cause would be of very brief duration. In practice I find it better to arrange my electrodes so that the more stimulating skin effects are felt by the patient in the neighbourhood of the seat of greatest pain, thus obtaining a counter-irritating effect, and at the same time satisfying the patient, who seldom appears happy unless she feels 'something going on' near the seat of the pain.

To what, then, are the benefits due which undoubtedly result from a prolonged passage of a strong continuous current through the tissues?

In order to answer this question satisfactorily the theory adopted should show:

1. That the electrical current produces a certain effect.
2. That this effect is such as is likely to result in benefit

in those cases for which an improvement from a prolonged administration of a strong galvanic current is claimed.

3. That the prolonged administration of a continuous current of high intensity is followed by such an improvement in the affected part as would be expected from the alleged action of the continuous current.

The theory which I propound is that the beneficial effects, resulting from the passage of a continuous current through the tissues of the human body, are *mainly* due to the heat generated in the tissues by the passage of the current, and the increased temperature in the affected part which results from this increase of temperature.

1. That an appreciable increase of temperature would be generated in a limb by the passage along it of a current of 100 milliamperes for thirty or forty minutes would be foretold by any physicist. That such an increase of temperature does actually occur can be confirmed by any electrotherapist when treating a case of sciatica by a continuous current of high intensity longitudinally applied along the length of the limb ; for if he applies the palm of his hand to the knee of the treated side he will find that it is perceptibly warmer than the knee on the other side.

In order to obtain objective, in place of subjective, evidence on this point, I have performed the following clinical experiments.

My method for the treatment of sciatica by the continuous current often consists in applying the negative pad, about 7×5 inches, to the sacro-iliac articulation on the affected side, and a positive pad round the foot, ankle, and lower third of the leg. The pads are soaked with a weak solution of sodium chloride, and a current as strong as the patient will tolerate is passed for forty minutes.

A current strength of from 80 to 110 ma. is often reached by the end of the treatment.

In order to find the increase in the skin temperature

resulting from this method, I secured, by means of a rubber strap, a surface thermometer to the skin, a quarter of an inch above and to the outer side of the patella. As the result of several experiments of this kind, I find that the skin temperatures in these cases usually rises from 2 to 4° F., varying with the intensity of the current and the duration of the treatment.

The following is a typical case :

Mrs. G. Sciatica of right leg. Pads arranged, and treatment administered by continuous current as above described.

Time in minutes.	*Temperature of affected leg.*	*Milliamperes.*
0	Thermometer shaken to zero	0
5		
10	89° F.	20
15	90	30
20	91	50
25	91·6	60
30	91·8	70
35	92	80

The diathermy current in this case was then applied with the following result :

5	94·2	700
10	98·4	900

The following control experiment was taken on the sound leg :

0	Zero
5	91° F.
10	91
15	91

The control on the sound side shows that the thermometer employed took five minutes to reach its correct reading. In taking the temperatures in cases of sciatica I have frequently found that the skin temperature on the affected side is often 2° F. lower than on the sound side.

I found that the ohmic resistance of a man's leg with the pads arranged in the way described was at the end of a treatment 500 ohms.

The equation, in accordance with Joule's law: $I^2RT \times 0{\cdot}24$ would be $0{\cdot}1^2 \times 500$ ohms $\times 2400$ sec. $\times 0{\cdot}24 = 2{,}880$ calories. Thus a considerable amount of heat is generated in a leg treated in this manner for forty minutes (2,400 seconds) with a current of 100 ma. This amount is, however, in excess of the amount usually obtained, as the current intensity of 100 ma. is not reached in the early part of the treatment.

2. How does this theory of the increased production of heat in the deeper structures and through the entire length of a limb or part of the body explain the beneficial effects of this form of treatment and indicate its adoption in, for instance, that vast field of medicine included under the modern title of ' fibrositis ' ?

Let us accept the theory that this condition is due to a toxæmia caused by some bacterial infection, though the bacteriologists are by no means agreed, either in regard to the type of bacteria, or to the method of infection.

Now most medical men will admit that this form of toxæmia becomes active and produces the symptoms characteristic of fibrositis when the vitality of the patient or the part affected becomes lowered, either by strain, accident, worry, damp, over-fatigue, or other exhausting cause. It will, moreover, generally be found that the affected part in chronic cases is colder and has a feebler circulation than normal, and it is a matter of common knowledge that fibrositis becomes more common as the resisting powers of the patient diminish with advancing years.

As Hanot puts it, ' Tout ce qui affaiblit prédispose.'

I claim that the continuous current by raising the temperature of the limb or part of the body, in the way I have indicated, and by the increased blood supply, which results from the increase of temperature, follows

the lines of treatment indicated by the conditions mentioned. Moreover, I claim that the increased vitality and nutrition of the tissues, thus excited, tend both to cure the disease and to guard against its recurrence.

3. To illustrate the effects of prolonged treatment by the continuous current, let us take the case of rheumatoid arthritis of the knee joint. This joint lends itself better than any other to the concentrated action of intensive galvanism, and, in my experience, yields better results from electrical treatment than any other joint. As I have already pointed out, such a joint before treatment is swollen, thickened, painful, tender, fixed, or limited in its range of movement, the skin is glossy and denuded of hair, and the patient is unable to walk. After a period of treatment, varying from a fortnight to six months, according to the severity and duration of the complaint, the pain has ceased, the thickening has decreased, and the joint is far less swollen, it is more free, and in some cases has fully regained its mobility ; the skin has regained its normal texture, there is, perhaps, even an overgrowth of hair on the part ; and finally the patient is able to walk.

Such are the results, I submit, that we should expect from the increased blood supply resulting from the application of the galvanic current. If the resulting reduction in swelling and thickening were due to an electrolytic action, we should reasonably expect, at any rate, a temporary increase of pain and inflammation. On the contrary, we find that one of the first benefits obtained is a decrease of pain, and this may be explained by the relaxation of tension resulting from the increase of the temperature of the joint.

We thus see that a considerable increase in temperature results in a limb treated by intensive galvanism. Such an increase in temperature leads to an increased blood supply. The beneficial results produced are such as would be expected from increased nutrition and increased

cellular activity consequent upon an increase in the blood supply of the affected part.

It may be urged that if the generation of heat within the tissues is so beneficial, it would be better to utilize the more powerful heat-producing action of the diathermy current. But it does not necessarily follow that because a method of raising the heat of a part to its normal, or even slightly above its normal temperature, is beneficial, that therefore it is advisable to raise its temperature to fever heat. Practical experience shows that the two currents, the continuous galvanic and the oscillating diathermic currents, have each their sphere of action. In old-standing chronic conditions, where the local circulation and nutrition need improvement, the best results are obtained from the galvanic current. But acutely painful conditions, especially those attended with spasm, yield most readily and quickly to the more intense heat of diathermy, which quickly relaxes the spasm and hence relieves the pain. Considerable tissue waste necessarily attends the employment of intensive diathermy, and the golden rule of therapy, that it is better to produce a gentle action for a prolonged period than an intensive action for a short time, certainly holds good here. When I have applied weak diathermy currents, not exceeding 300 ma., for thirty or forty minutes longitudinally through the limb in sciatica, I have found little difference in the results obtained from those yielded by the constant current for a similar period. Perhaps the best results are obtained by administering a diathermy current of moderate strength for about ten minutes, until the limb feels perceptibly warm to the touch, then continuing the treatment with intensive galvanism for a further period of thirty or forty minutes. When I have treated the sciatic limb for about ten minutes with a strong diathermic current of from 700 to 900 ma. the results have not been by any means so good.

But does the continuous current in its interpolar course

between the electrodes produce no other effects beyond those of heat? Has the bombardment of the cell constituents by millions of ions, with a force capable in the aggregate of producing an appreciable degree of heat, no stimulating effect on the activity of the cells themselves? It seems reasonable to suppose that this 'ionic massage' must have some such effect. It is a difficult matter to prove, and I would prefer to base the therapeutic claims of the galvanic current upon the surer and more evident basis of heat production. In this connexion Professor Soddy propounds an interesting question in his book (3), *Matter and Energy*: 'Have the minute cells of the body the power of taking advantage of the difference in the temperature of the molecules bombarding them, and when one comes along at more than the average speed, absorbing it and its energy, building up a larger cell thereby, which in course of time undergoes metabolism and evolves again its store of energy?' This is, as Professor Soddy states, a fascinating and legitimate line of inquiry, but it is an enigma of which I will not attempt to offer a solution.

Hitherto we have been solely discussing the interpolar action of the continuous current; but there is little doubt that the polar action of the continuous current at the pads is of considerable importance, especially in increasing the blood supply and the nutrition of the skin in chronic cases. This polar action may contribute in no small degree to the continuous current being more beneficial in chronic cases than the diathermy current, for the latter has, of course, no polar action.

In the typical case of rheumatoid arthritis, quoted above, the trophic improvement in the condition of the skin is probably in a great measure due to this polar action of the current.

It is important to realize that the polar action of the galvanic current is of two kinds, the one a primary or direct action, the other a secondary or indirect action.

The primary or direct action is due to the direct destruction, dissociation, or splitting up of the tissues in contact with the poles, by electrolysis. The secondary or indirect effects result from the action of the products of this decomposition on the tissues. Thus with non-polarizable electrodes, such as platinum, an acid will be formed at the positive pole, and an alkali at the negative, as is seen in the litmus paper test for polarity. With polarizable electrodes, such as zinc, a salt, in this case the oxychloride of zinc, will be formed in a nascent state at the positive pole. With a sufficient strength of current the chemical action of these products on the tissues in the neighbourhood of the poles is a very important one.

In treating cases by what we may term medical galvanism, these two actions are avoided as much as possible by the employment of currents of low density, otherwise serious burns of the skin would result. But there is always some irritation of the skin caused by the electrolysis at the poles of the substances which are employed to moisten the pads, and within certain limits the action of these products is beneficial in stimulating the blood vessels of the skin, both directly and reflexly, and so producing an increased blood supply of the surface with its attendant benefits.

By the foregoing reasoning, based upon experience and experiments, we arrive at the conclusion, that the continuous current, by the chemical changes which it excites at the pads, both directly and reflexly stimulates an increased blood supply of the skin, and by the increased heat production in the tissues an increased blood supply results throughout the whole of the interpolar path, inducing nutritional and other therapeutic effects of the greatest value and importance.

Moreover, there is reason to suppose, though the proof is not forthcoming, that the bombardment of the tissue cells by millions of ions in the path of the current must occasion an increase in the functional activity of those cells.

The Surgical Application and Action of the Constant Current

The polar action of the continuous current is discussed above solely in relation to its medical application. In surgical treatment both the direct electrolytic effects of the current and the action of the nascent products of this electrolysis are of great importance.

By inserting a negative electrode, in the form of a fine platinum needle, into a hair follicle, the roots of superfluous hairs can be electrolysed, the follicle destroyed, and the hair epilated. This process is in the main an electrolytic one, though it is true that a caustic alkali is also formed in the neighbourhood of the electrode, and doubtless assists in the destructive process.

A somewhat similar method is very useful in the treatment of septic sinuses ; a zinc probe is passed into the sinus and attached to the positive pole of the battery. In this case, some electrolysis of the tissues occurs, but the more important action is that of the nascent oxychloride of zinc, the product of the electrolysis, which exercises both a destructive and an antiseptic action on the lining membrane of the sinus. Lupus nodules may be successfully treated in similar manner by the introduction of a zinc needle and the application of 3 or 4 milliamperes for a few minutes.

Another application of this treatment affords us one of the most valuable methods in the whole range of electrotherapy. In cases of chronic endometritis with a septic discharge, a uterine probe of zinc is introduced into the uterus, connected with the positive pole of the battery, and a current of 20 to 30 milliamperes is passed for fifteen or twenty minutes. No anæsthetic is needed. Any slight pain that may be caused can be allayed by a reduction in the strength of the current. In this case the nascent oxychloride of zinc pervades the whole surface of the mucous membrane, permeating to every

crypt and follicle, thus destroying it more intimately and completely than can be done by the most thorough curetting. One cannot help reflecting how much better nature's arrangements are than those suggested by some electrotherapists, for were the theory of deep 'ionic medication' a true one, the whole body of the uterus would be destroyed by the action of the zinc ions.

I am convinced, both by my experience of this treatment and from my past experience of curetting, an operation which I often performed when engaged in general practice, that the electrical method should invariably be preferred, except in those cases where there is reason to suspect the presence of placenta remains.

The same method can be successfully adopted in the treatment of some cases of metrorrhagia : in such cases it is advisable to use a copper probe in place of a zinc one, on account of the more styptic action of the oxychloride of copper.

The hyperplasia of the uterine mucous membrane is thus destroyed, and a cure effected in uncomplicated cases. I have known similar treatment successful in a case of recurrent miscarriage where the patient had several times been curetted on account of this trouble without any benefit, and had tried every precaution to prevent the recurrence of the abortion, but without effect. She took no unusual precaution during the next pregnancy after the electrical treatment, and a healthy child was born at full term. The only explanation that I can offer for the success of the treatment, after the repeated failure of curetting, is that a diseased condition of the uterine mucous membrane had been more thoroughly removed.

Attempts have been made by writers on 'Ionic Medication' to show by test-tube experiments that this polar action is the result of the electrical introduction of ions. A careful examination of these experiments will show that the alleged 'ionic' action ceases at the interposition of any medium of a different character from that of the

solution in contact with the active electrode, and the real facts revealed by these experiments show that the action is solely a polar one, namely, that it results from the action of the products resulting from the electrolytic action that occurs at the poles.

Though the destructive action of the products of electrolysis is so clearly seen on superficial tissues, and though it is easy to realize the lethal action that such products must exercise on neighbouring bacteria, nevertheless, another theory has been propounded to account for this antiseptic action of the constant current.

If we pass a constant current through a capillary tube containing water, the water is electrically repelled towards the negative pole : but if the glass is coated with vaseline, the displacement of the water occurs in the direction of the positive pole In the one case the water is positively charged in relation to the glass, and in the other it is negatively charged in relation to the vaseline.

Likewise, small particles of powdered glass suspended in water, blood corpuscles suspended in organic liquids, and microbes in cultures carry an electrical charge and can be similarly transported by the constant current. Some kinds of microbes possess a positive charge and are transported towards the kathode, others have a negative charge and undergo electrical transport towards the anode.

It was hoped that this phenomenon might be of use for the purpose of differentiation between different kinds of microbes, or for separating the different kinds of germs present in the same culture. But unfortunately the electrical charge varies in amount in different breeds of the same kind of bacteria, and is often very small ; sometimes even the microbes will start off gaily under the influence of the current in one direction, then stop, and afterwards set off in the opposite direction.

This phenomenon of electrical transport has not yet, I believe, been found to possess any practical value, though it is thought probable that this electrical charge

of the particles may have some bearing on the phenomenon of osmosis through cellular walls (4).

It has been suggested that this electrical transport of germs may account for the curative action of the constant current when applied to the urethra in cases of gonorrhœa, the suggestion being that the gonococci carry a negative charge and are consequently attracted to the positive pole placed in the urethra; the increased urethral discharge which accompanies and follows the application of the treatment is cited as evidence of such a flow. This increased discharge is, of course, more readily accounted for by the stimulating action of the current on the cells of the urethral glands.

The high voltage necessary to displace the cocci from the crypts and follicles of the urethra, or to propel or attract the relatively large pus cells, appears to have been overlooked by the propounders of this theory. Certainly a new and vast field of electro-pathology would be opened up if it were possible by the 'transport électrique' to regulate the movements of the blood corpuscles and germs within the tissues of the body.

The destructive properties of the electrolytic products certainly offer a simpler and more probable explanation of the antiseptic properties of the galvanic current.

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CHAPTER II

THE THERAPEUTIC ACTION OF INTERRUPTED CURRENTS OF LOW FREQUENCY

In the previous chapter the galvanic current was discussed solely in relation to that form of it which, between the periods of make and break, maintains a constant and unvarying strength.

If the galvanic current is suddenly made or broken, or if its strength is suddenly varied, entirely different effects are produced. These effects appear to be attributable to the velocity of the hydrogen ion being five times as fast as that of any other kation, and two and a half times as fast as that of any anion.

When an electrical current is suddenly passed through an electrolyte, such as that with which the human tissues are bathed, the hydrogen ions, being so much the faster, are immediately drawn ahead of and, as it were, away from the electrostatic attraction or inhibitory influence of the more slowly moving anions. A sudden concentration of hydrogen ions thus occurs in the neighbourhood of the kathode, and by the chemical stimulation which results therefrom the nerve or muscle substance is stimulated and a muscular contraction is excited. When the strength of the current remains constant, equilibrium of ionic concentration is quickly re-established, the contraction ceases, and the muscle remains at rest ; until by a sudden increase in the strength of the current a similar concentration recurs, resulting in another contraction of the muscles in the neighbourhood of the negative pole. At the break of the current, or at a sudden diminution of its strength, a muscular contraction is excited at the positive pole.

At first sight we might suppose that this contraction occurring at the break of the current in the neighbourhood of the positive pole was due to the sudden accumulation of anions in this region, a result that we might visualize as due to the heavier anions coming to rest more slowly than the lighter kations of hydrogen. This, however, is not the view entertained by physiologists. Professor Bayliss (1) gives the following explanation: 'How then is the fact of excitation at the anode, which occurs on breaking the circuit, to be explained? It is pointed out by Keith Lucas (1912, p. 519, Croonian Lecture, *Proc. R. S.*) that "the one feature which is common to the cathode when the current is made, and the anode when the current has just ceased to flow, is an increase of the concentration of kations above the value which occurred at each of these points immediately before". At the anode, however, the concentration of kations only rises to its normal level by diffusion, after having been decreased. Nernst and A. V. Hill give what is essentially the same explanation on the ground of the "combination" of ions with some substance in the nerve. During the passage of the current, the diminished concentration of kations at the anode results in a different equilibrium in the reversible "compound", or absorption, between the ions and the assumed substance. When the current ceases to flow, there is a sudden concentration of kations in the system in excess of that with which it was previously in equilibrium; a condition which is the same as that at the kathode when the current is first established. Thus the excitation at the anode and the failure of slowly rising currents to excite appear to depend on the same conditions. It will be clear that more experimental work is required before the question can be settled.'

It has been demonstrated by the experiments of Cardot and Laugier (2) on the sciatic nerve of the frog, and by the experiments of Bourguignon (3) on human nerves and muscles, that at the make of the current it is the negative

pole which is alone active ; and at the break of the current it is the positive pole only which excites contraction. The so-called Anodal Closing Contraction (A.C.C.) is a 'virtual' Kathodal Closing Contraction (K.C.C.) situated deeply in the tissues or the substance of the muscles ; and the so-called Kathodal Opening Contraction (K.O.C.) is a 'virtual' Anodal Opening Contraction (A.O.C.) similarly situated. It is therefore incorrect to speak of such a current as K.O.C., or A.C.C., and the formula so frequently quoted, K.C.C. > A.C.C. > A.O.C. > K.O.C., has no real justification. Since K.O.C. and A.C.C. are respectively A.O.C. and K.C.C. deeply diffused in the tissues, their density is consequently diminished, and the resulting contraction is of a diffused and weakened character.

To obtain the necessary concentration of ions for the excitation of a contraction, two conditions are required. 1. The current must have a certain minimal strength, or no contraction can be excited. 2. The current must have a certain minimal duration, below which a current of a given strength will not excite a contraction. If the minimum duration of a current of the minimal strength is reduced, no contraction will result ; and as the duration is decreased the minimal strength of the current has to be increased in a rapidly increasing ratio. The converse of this holds good, and if the voltage of a current is increased, a contraction is obtainable at a lower intensity.

The contractions occurring at the make and break of a galvanic current are single contractions, and while the current is maintained at an even strength no further contractions result. The single snatch of a muscle which is thus obtained is not of the best type for ordinary therapeutic purposes. A physiological contraction is of a tetanic type resulting from the rapid succession of repeated stimuli, occurring not less frequently than about twenty a second. In order to excite contractions of this physiological type, the faradic coil is usually employed. In this instrument a rapidly vibrating trembler blade

makes and breaks the primary current fifty or more times a second. This interrupted current passing through the primary coil induces a secondary current of similar frequency, but of very brief duration and of far higher voltage in the secondary coil.

This increased voltage in the secondary is proportional to the increased number of turns or coils of wire in the secondary coil. As the voltage is increased in this way, the intensity of the current is correspondingly decreased. The faradic current at break is in a contrary direction to that at make, and is so much more powerful that for practical purposes the current at make may be disregarded. The faradic current differs from an interrupted galvanic current in the following respects: the voltage is far higher than that ordinarily applied in galvanism; polar action is absent, for the amount of current that passes at make being less abrupt takes longer to flow; and so, though its voltage is lower, an equal amount of current passes at each interruption, distributed over a longer period, with the result that the polar effects of the current at make neutralize the polar action of the current at break, and vice versa. There is, however, this similarity between the action of the two currents, that, provided it is interrupted with sufficient rapidity, a tetanic contraction can be excited by the galvanic current. Such a tetanic action can be readily obtained by the ingenious arrangement known as the Frimandeau Coil. This is an instrument that utilizes the magnetic attraction of the core of the primary coil of the faradic to interrupt the galvanic current. The current so obtained has one definite advantage over the secondary current from a faradic coil. The current obtained from the usual clinical type of faradic coil has a duration of only about 1/1,000 of a second: the duration of the current from the Frimandeau coil may, on the other hand, be varied within wide limits by the adjustment of its interrupter. The duration of the faradic stimulus is too short to excite a contraction

in a muscle, the nerve of which is not functioning, but the interrupter of the Frimandeau coil may be so adjusted as to give interruptions of sufficient frequency to excite a tetanic contraction, and of sufficient duration to stimulate a paralysed muscle. The current from such an instrument has polar action, and, its voltage being lower, the intensity needed to excite a contraction, corresponding in range to that from a faradic stimulus, must necessarily be greater. On account of the lower voltage employed, the contraction excited by the Frimandeau coil is less painful than that from the faradic coil; moreover, being unidirectional, it admits of measurement by an ordinary galvanometer.

The high voltage of the current from the faradic coil can be utilized to excite counter-irritation of the skin: in this case the current is best applied by means of a wire brush or Tripier's 'râteau'. This skin effect is, however, far better obtained from a high frequency apparatus of tension or a static machine.

The faradic current may hence be regarded for therapeutic purposes mainly as a means for the artificial stimulation of muscular contraction and muscular exercise. Its use is indicated in that large class of cases where muscular exercise is likely to be beneficial: in cases of obesity, of wasted or flabby muscles, of dilated heart, of œdema of the extremities, in certain cases of rheumatism, constipation due to laxity of the abdominal walls, and a variety of similar conditions.

In its application for the excitation of muscular contraction, the faradic current should alternate with periods of rest several times a minute, $\frac{2}{5}$ duration of current to $\frac{3}{5}$ rest is a safe rule. Otherwise, were the current applied with no intervals, the muscle would be over-fatigued, and more harm than good would result from the treatment. It may be interrupted and restarted, either suddenly and abruptly as by a metronome, or in a graduated wave or surge, either manually or instrumentally.

The work of Rowley Bristow has shown how, and with what benefit, individual muscles may be developed; and the very important work of the distinguished electro-therapist, Professor Bergonié, of Bordeaux, has demonstrated with what advantage generalized muscular contraction throughout the whole body may be utilized as a curative agent. Professor Bergonié's method was originally introduced for the treatment of obesity, in which condition about a pound of weight or more is lost by a fat patient as the result of the fat being burnt up in the energy expended by the muscular contractions during a single treatment. The loss in weight is accompanied by an increase in the muscular tone and development, and a marked improvement results in the general health of the obese patients. This treatment has recently been extended to many other conditions, and is of special value in the treatment of dilated hearts associated with a general deficiency in muscle tone, for the muscles of the body can be exercised by this method without any muscular strain or nervous effort on the part of the patient, the rate and vigour of the contraction being under the complete control of the operator.

The alternating and sinusoidal currents in their therapeutic action closely resemble the faradic current. The name alternating implies that the direction or polarity of the current alternates from positive to negative, and vice versa; these alternations are usually at the rate of about fifty times a second. In consequence of this alternation the polar effects of the current mutually neutralize one another. The term sinusoidal implies that this variation in direction occurs gradually in the form of a 'sine', or wave-like, curve. Wave-like contractions can by this means be excited in the muscles, varying in degree according to the strength of the current, from a gentle tremor to a vigorous contraction.

The therapeutic action of interrupted currents, such as the alternating and sinusoidal, differs from that of the

continuous current in some very important respects. Since in currents with frequent reversals of polarity the polar action is neutralized at each alternation of direction, little or no therapeutic effect will result from this cause. Again, owing to its intermittency the heating effect on the tissues will be far less with the alternating than with the continuous current. The therapeutic action of interrupted currents is mainly due to the recurrent hydrogen ion concentration which results from their intermittency. At each make and break, at each sudden variation in their strength, a concentration of ions occurs throughout the tissues, and this, though it may not be of sufficient amount to excite a muscular contraction, has nevertheless a stimulating effect on the cells of the body. Dr. Barclay, of Manchester, published during the war some very interesting results that he obtained from treating cases of un-united fracture by the sinusoidal current. By a series of radiographs he was able to show the extent to which callus formation was increased by the treatment.

As the result of this recurrent ionic concentration, the alternating are far more dangerous than the continuous currents, and fatal accidents occur at considerably lower voltages with them.

Alternating and sinusoidal currents, owing to the ionic concentration that they excite, should never be employed in regions near the heart. In Germany several deaths have been recorded from fibrillation of the cardiac muscle excited by even the small sinusoidal currents derived from machines of the pantostat type.

Further investigation is required before we can decide dogmatically between the relative therapeutic merits of the continuous and the interrupted currents. In the present state of our knowledge it would appear that for the treatment of rheumatism, sciatica, neuritis, etc., the thermic and polar effects of the continuous current would point to the choice of this method. On the other hand,

in the treatment of severe nerve injury, anterior poliomyelitis, or un-united fractures, the stimulating effect on the tissue cells of the sinusoidal or alternating currents would be preferred by many electrotherapists.

Some very remarkable results have been claimed for a form of interrupted current, known as the Leduc current. The Leduc interrupter is an instrument that admits of the interruption of the galvanic current up to 200 times a second, the best results being obtained at about half that rate of interruption. It is claimed that by employing this form of interrupted current it is possible 'to produce gradually with remarkably weak currents single contractions, tetanus, local anæsthesia, general anæsthesia, paralysis of the respiration, of the heart, and ultimately death'.

Leduc claims to have produced all these results when experimenting on animals, prolonging the anæsthesia for eight hours in some cases without producing any bad effect. He has also, when experimenting on himself or his assistants, produced anæsthesia and 'electric sleep'. The intensity of the current does not exceed three or four milliamperes, and the potential is only from ten to twenty volts.

There does not seem to be anything occult in these experiments; their chief scientific interest lies in the fact that they show the cumulative effect of the recurrent ionic concentration excited by very weak currents when rapidly interrupted. Whereas, with interrupted currents of high or even moderate intensity, a sudden inhibition of respiration or cessation of the heart beat would occur, on the other hand, when using a current of low tension and intensity, we are able, in consequence of its cumulative action, slowly and gradually to produce in animals these results, and at the same time can differentiate the various stages produced by its action.

Electrotherapists, who have succeeded in producing cutaneous anæsthesia upon themselves in this manner,

tell me that the procedure is a very painful one; the anæsthesia is, moreover, by no means easy to produce, and physiologists frequently fail to obtain it in laboratory experiments. The anæsthesia, local or general, would appear to be due to an over-fatigue of the sensory organs in the one case and of the brain cells in the other. The local anæsthesia is in many respects identical with that obtained by rapidly and repeatedly percussing a skin area.

The Leduc interrupter can be utilized for electro-diagnosis of nerve and muscle injuries, and is very convenient for this purpose, as by its use the duration of the current can be readily regulated, and its intensity can be measured by a milliamperemeter.

These currents are useful in the treatment of certain forms of neuritis. In causalgia, in my experience it far surpasses all other forms of treatment, relieving for several hours the intense pain of this terrible condition with such certainty as to have even a diagnostic value. It appears possible that by the repeated stimulation of the hydrogen ion concentration, resulting from this treatment, the sensory organs, already in a state of hyper-activity, may become exhausted and so anæsthetic; in a way analogous to that in which the recovering end-plates of motor nerves in peripheral nerve lesions become readily over-fatigued and inexcitable, when subjected to too frequently repeated electrical stimulation.

We have seen that, provided the galvanic current is applied to a limb with very slow gradation from zero to the maximum strength employed, no muscular contraction will be excited; but if the current is applied rapidly or suddenly, a contraction at once results. As a current increases to its maximum more and more gradually, so the efficiency of the resulting contraction diminishes, until no contraction results. Lapicque has shown that paralysed muscles, needing a larger stimulus to excite them and a longer duration of the minimal strength of

this stimulus than normal nerves and muscles, are less adversely affected than the latter by a retardation in the onset of the current.[1]

Though, for instance, a current which reaches the minimum exciting strength in about 1/200 second may fail to excite a contraction in a healthy muscle, yet a current which takes as long as 1/20 second to reach the minimal exciting strength may nevertheless stimulate a contraction in a paralysed muscle. On these principles Lapicque has introduced an instrument (Fig. 6) by means of which the current reaches the necessary strength so gradually that the paralysed muscles are excited to contract, while the healthy muscles remain unexcited. This is a most valuable result, for not only is all fear of the over-action of the healthy muscles entirely eliminated, but also the isolated contraction of the affected muscles has a most valuable re-educative effect on the patient in recovering nerve lesions. For by this means the movement that the patient has to re-educate himself to perform is clearly demonstrated to him.

Lapicque produced this retardation of the onset of the current by means of condensers. For the application of this treatment, the following apparatus is needed: a source of constant current supply; an arrangement for regulating the current, either a graphite or a water resistance, a wire-wound resistance must not be employed, on account of the secondary induction which would be set up by use. There is also needed an instrument, such as a metronome, for interrupting the current, and finally a set of fifteen condensers [2] of 2 M.F. capacity placed in

[1] 'If a current reaches progressively its constant intensity, the diminution of its efficiency, which is the result of this slowness of make, is smaller as the chronaxie is longer' (Lapicque, *Académie des Sciences, Comptes Rendus*, November 22, 1915).

[2] 'A condenser of 1 M.F., placed in parallel, causes the current to take about 3/1,000 second to reach 95 per cent. of its intensity constant' (Lapicque, *Académie des Sciences, Comptes Rendus* November 22, 1915).

parallel with one another and in parallel with the patient. These condensers should be fitted with a selector enabling any multiple of 2 M.F. capacity to be employed up to the

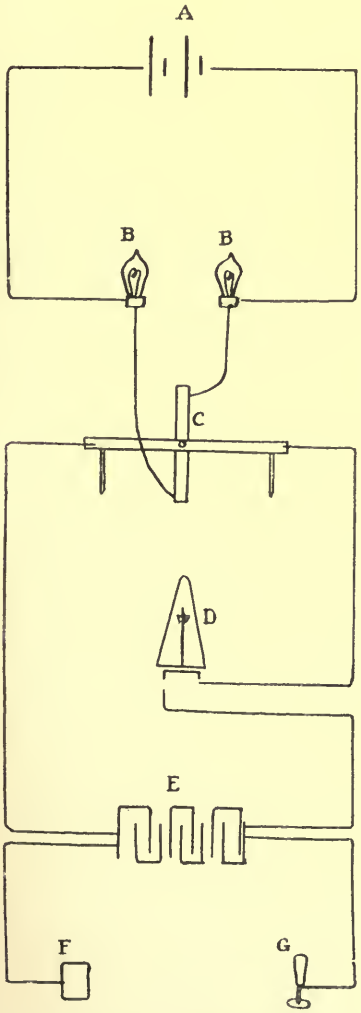

FIG. 6. A modification of Lapicque's instrument for the selective stimulation of paralysed muscles.

maximum of 30 M.F. The larger capacities are employed, as the hypo-excitability of the patient's muscles necessitates the employment of a stronger exciting current. The apparatus operates in this manner; at the make of the current a gradually decreasing amount of the current, which would otherwise have reached the patient, is diverted into the condensers placed in parallel with him, until they become fully charged, when the full current passes to the patient.

When the metronome breaks the current, as there is no path for the condenser discharge except through the patient's circuit, the condensers discharge with a gradually decreasing intensity in the direction of the current of make, and so damp or lengthen the current of break in proportion to the condenser capacity employed. A gradually progressive current both at make and break is thus obtained.

A somewhat similar effect, but one which is not capable of such easy and effective adjustment, can be obtained from certain types of surgers.

It is convenient to regard, from the therapeutic point of view, condenser discharges as a form of interrupted current; for by repeatedly charging and discharging a condenser a result is obtained in many respects identical with that from making and breaking a galvanic current. By charging and discharging a condenser through a patient at intervals longer than twenty a second, distinct and isolated contractions are obtained; or the condenser may be charged and discharged with such frequency that a tetanic contraction results. By means of the so-called Static Induced Current of Morton an isolated or a tetanic contraction can be obtained as desired. The character of a condenser discharge depends upon the resistance offered to the discharging current. If the resistance in the circuit through which the discharge takes place is negligible or very slight, the current rushes from the condenser so rapidly that it over-discharges itself, and then

oscillates so rapidly with decreasing amplitude, before it finally comes to rest, that it gives rise to a high-frequency current in the manner described in the next chapter.

But, if the current from the condenser discharges through a high resistance, the discharge takes place in an unidirectional wave falling in voltage rapidly at first and then gradually subsiding to normal. The duration of such a discharge is in any case very brief, varying with the capacity of the condenser, the voltage at which it is charged, and the resistance through which the discharge takes place.

A condenser of 0·016 M.F. capacity charged at a potential of 100 volts, discharging through the resistance usually offered by the human skin, takes about 1/24,000 second to discharge. A condenser of one farad capacity is one which is raised to a potential of one volt by a coulomb of electricity. In medical electricity we employ micro-farads and their fractional parts, the micro-farad being 1/1,000,000 of a farad. The amount of current which is employed is therefore extremely small, but owing to the high potential used a condenser of 0·025 M.F. charged at 100 volts is capable of exciting a contraction in a normal muscle.

Condenser discharges are recommended by some electrotherapists for the purpose of electro-diagnosis; they are especially useful perhaps in examining cases of infantile paralysis, the smaller condenser discharges being less painful than the faradic current. The degree of paralysis can within certain limits be roughly estimated by the use of discharges from condensers of varying capacity.

The use of condenser discharges has from time to time been recommended in electrotherapy, but it is difficult to understand what advantages their employment possesses over the less complicated faradic coil, the latter having the advantage of being more readily adjusted to excite a tetanic contraction, and also in yielding no polar action on the skin, though such polar action must be very

small with condensers, on account of their small capacity. The most important therapeutic effects from condenser discharges are those obtained from the static induced currents of Morton, in which the enormously high potential employed enables certain effects, which are discussed in the chapter on Static Electricity, to be conveniently obtained.

The Watteville Current is a faradic current reinforced by a constant current flowing through the secondary of the coil in the same direction as the current of break (the Watteville Current 'in tension'). If the direction of the constant current is reversed, its effect is to weaken the action of the faradic current (the Watteville Current 'in opposition'). As ordinarily applied, a faradic coil is inserted in a galvanic circuit, so that the positive pole of the faradic secondary at break is connected with the negative wire from the galvanic battery, and the positive of the battery with the negative of the secondary coil. The current from the battery in this case flows in the same direction through the secondary of the coil at break; it thus enables a faradic contraction to be excited with less sheathing of the primary, and, consequently, at a lower voltage, and with less pain, an effect of the same character as is obtained by replacing a finely wound secondary by one wound with coarser wire. The Watteville Current 'in tension' is recommended by some writers for the excitation of involuntary muscular fibres. It is a useful method of obtaining a faradic contraction at low voltage, and excites a very efficient form of muscular contraction when suitably surged.

The Watteville Current in opposition is very little employed; the higher voltage necessitated by its use is more painful and thus excites greater counter-irritation of the skin.

A constant current may be interrupted suddenly and abruptly, as by a metronome, or by a switch; or it may be gradually increased in strength to the maximum from

zero, and gradually back to zero ; when applied in this manner it is said to be ' surged '.

Either the metronome or the surger may be so arranged as simply to make and break the current, or they may be adapted to reverse the direction of the current each time it is interrupted, and so obviate polar action on the skin.

On general grounds the metronome method of interruption is to be preferred for the excitation of a powerful and sudden type of contraction ; for, since there is in this method no retardation of the onset, the resulting contraction is more efficient.

The surging method should be selected when a gradual, painless, and wave-like contraction of the usual physiological type is desired. The sudden quick contraction excited by the metronome appears to be more suitable for the treatment of obesity, and the slow surging method of interruption for the development of muscle.

An instrument for the surging of therapeutic currents should fulfil the following requirements :

(1) It should admit of wide variation in speed, a slow speed for surging the faradic and sinusoidal currents, and a faster surge, readily regulated, to admit of its employment in place of the Lapicque condensers for the selective stimulation of paralysed muscles.

(2) It should admit of the polarity being reversed at each interruption, in order to obviate polar action on the skin.

(3) It should allow of a definite and adjustable period of rest between each stimulation.

(4) It should allow of the current remaining at its maximum for a definite period, the duration of which should be capable of regulation.

In order to meet these requirements, I have designed an instrument (Fig. 7), electrically driven, which admits of its speed being regulated, (1) by three steps in the relation of the driving pulley to the driven pulley, (2) by adjusting a friction disk drive, (3) by regulating the rheostat of the driving motor.

A horizontal vulcanite disk, revolving in a bowl of water, bearing two contact wires, reverses the polarity, if desired, at each interruption, and both the periods of rest and maintenance of maximum intensity can be regulated by increasing or diminishing the length of these contact wires.

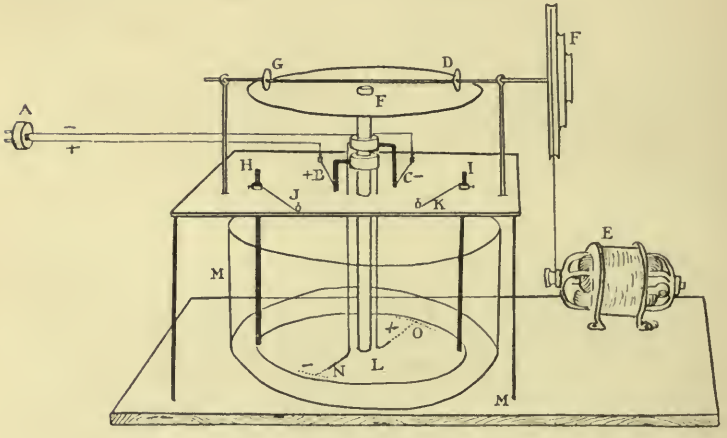

FIG. 7. The author's surger.

This instrument will be found useful for surging any of the forms of current described in this chapter; but for obtaining the very valuable graduated contractions by the Bristow method, it is certainly not the equal of the Bristow coil; in fact, I do not think that any mechanically operated instrument can replace the personal factor of the operator, which is so essential a part of Mr. Rowley Bristow's method.

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CHAPTER III

THE THERAPEUTIC ACTION OF INTERRUPTED CURRENTS OF HIGH FREQUENCY

As the outcome of his investigations on the physiological action of alternating and sinusoidal currents, D'Arsonval (1), in 1888, found that by increasing the number of interruptions or waves administered in tetanizing a muscle, the intensity of the phenomenon of excitation was correspondingly increased, until a maximum of from 2,500 to 5,000 excitations a second was reached; after this point an increase in the frequency caused a decrease in the degree of excitation. At that time D'Arsonval was using a Ruhmkorff coil, and was unable, owing to the time lost in magnetizing and demagnetizing the core, to obtain a sufficient frequency of oscillation entirely to suppress muscular contraction. In December 1890, using the apparatus of Hertz, D'Arsonval obtained 'billions of electrical excitations a second', and was thus enabled to suppress all muscular contractions, and hence was the first to demonstrate the characteristic phenomena of high-frequency currents.

The Hertzian apparatus, like the modern H.F. instruments, depended upon condenser discharges for the production of high-frequency waves.

A condenser, the simplest and best-known form of which is a Leyden jar, discharges itself in one of two very different manners. If the resistance through which it discharges is high, the current of discharge is of a slow, continuous, progressive, and unidirectional character (Fig. 8). If the resistance is negligible, the discharge is of an oscillating character, the oscillations being isochronous, and decreasing in amplitude in geometrical progression (Fig. 9). These two types of discharge have been

well compared to what takes place when two vessels filled with water are connected in the one case by a pipe of large diameter, and consequently of negligible resistance or friction; and in the other case by a pipe of small

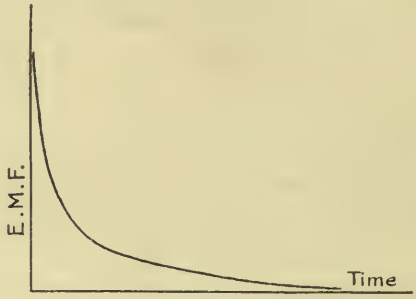

FIG. 8. Type of condenser unidirectional discharge through a high resistance.

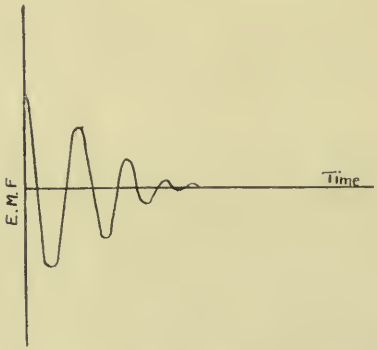

FIG. 9. Type of condenser oscillatory discharge through a low resistance.

diameter, which consequently offers considerable frictional resistance.

In the former case the water reaches the point of equilibrium, after overlapping it, in a series of progressively diminishing oscillations. In the latter case the point of equilibrium is slowly, steadily, and progressively

reached without at any time being overlapped. The first example serves to illustrate the type of discharge which is required to excite the very frequent oscillations necessary for the production of high-frequency currents. The latter illustrates the type of condenser discharge which is sometimes used for electro-diagnosis, and also for treating cases of paresis and paralysis by intermittent condenser discharges of low frequency : in such cases the discharge takes place through the high resistance of the body, and hence is of the continuous type shown in Fig. 8. The time occupied in the discharge of the condenser is proportional to the capacity of the condenser, the voltage with which it is charged, and the resistance through which the discharge takes place. Lord Kelvin has expressed these phenomena in the following mathematical formula : C is the value of the capacity, L the coefficient of the self-induction, and R is the resistance of the circuit.

If $R^2 > \frac{4L}{C}$ then the discharge is continuous.

But if $R^2 < \frac{4L}{C}$ then the discharge is oscillating.

When the resistance in the circuit is negligible, the duration of an oscillation is expressed by the following formula of Lord Kelvin :

$$T = 2\pi \sqrt{L \times C}.$$

D'Arsonval originally used a form of high-frequency apparatus designed by Elihu Thompson and Tesla, but subsequently adopted an instrument based on the design of an apparatus used by Sir Oliver Lodge for his experiments on lightning conductors.

In a paper entitled ' Action physiologique des Courants alternatifs à Grande Fréquence', published in the *Archives de Physiologie Normale*, 1893, D'Arsonval deduced the following physiological observations from his experiments :

1. That the tissues traversed by high-frequency currents became less excitable to ordinary excitants.

2. That a manometer placed in the carotid of a dog showed a fall of many centimetres under the influence of H.F. currents.

3. That after the current had been administered for some time, the skin became vascularized and covered with sweat.

4. That an increase in the respiratory exchanges occurred.

5. That a thermometer did not show any elevation of the ordinary temperature, the extra heat produced being lost by radiation and evaporation.

Brown-Séquard, according to D'Arsonval, studied the action of H.F. currents, and explained their failure to excite either muscular contraction or sensation as the result of inhibition.

It is rather remarkable that D'Arsonval in his original experiments was not more impressed by the amount of heat generated in the tissues by these currents. Although he passed as much as 3 amperes through his body, he merely states that 'if the current is very strong, one simply finds a little heat at the points of entry and exit of the current'. He appears at first to have formed the opinion that H.F. currents, like static charges, existed only on the surface of the body and could not penetrate to the deeper parts; he was probably led to this conclusion from studying the effects produced on a patient placed in the condenser cage, the 'grand solénoïde', in which case the electro-magnetic field attracted the currents to the surface of the body.

The predominance of the heating effects appears to have first occurred to Tesla, who stated that, as the results of his experiments, he was of opinion that it would be possible to maintain the temperature of a naked man at the North Pole by means of high-frequency currents. Nagelschmidt, of Berlin, was the first to make use of the heating effects of H.F. currents for therapeutic purposes to any real extent.

The chief alteration needed to convert the older type of H.F. apparatus to the newer form of diathermy instrument consists in a modification of the spark gap. In the earlier forms of apparatus the spark gap terminated in two small balls or points, separated by an inch or more. In the modern type of diathermy instrument this spark gap is replaced by two or more pairs of flat disks, separated only by a gap of about one millimetre. To prevent the current arcing across this short gap in a continuous stream, instead of oscillating across in a stream of sparks, the plates and the intervening gap must be kept cool. This cooling of the sparking plates was at first effected by attaching radiating flanges of copper to the plates, but better results are now obtained from the use of coal gas [1] as a dielectric between the plates. The type of spark gap does not affect the frequency of the oscillations, which depend on the self-inductance of the solenoid and the capacity of the condensers; but, with the flat disks, several trains of oscillations pass across from different parts of their surface at the same time, instead of the single train of oscillations which are obtained from gaps terminating in points. Higher amperage, and consequently greater heating effects, are thus obtained.

The practical result of the alterations of the spark gap is that with the older type of H.F. apparatus we obtained a current of higher voltage (higher tension) and lower amperage (lower intensity), and with the diathermy apparatus we obtain a current of lower voltage (lower tension) and higher amperage (higher intensity). It would be less confusing and more explicit if, as some French writers do, instead of distinguishing between High-Frequency and Diathermy currents, we spoke of the

[1] By replacing the air or oxygen in the gap with hydrogen derived from the passage of the sparks through coal gas, or the vapour of ether or alcohol, the gap is better cooled, hydrogen conducting the heat better than other gases. The smaller molecules of the hydrogen gas are more quickly ionized, and so the discharge takes place more quickly and abruptly (Broca).

former as High-Frequency Currents of Tension, and the latter as High-Frequency Currents of Quantity. The

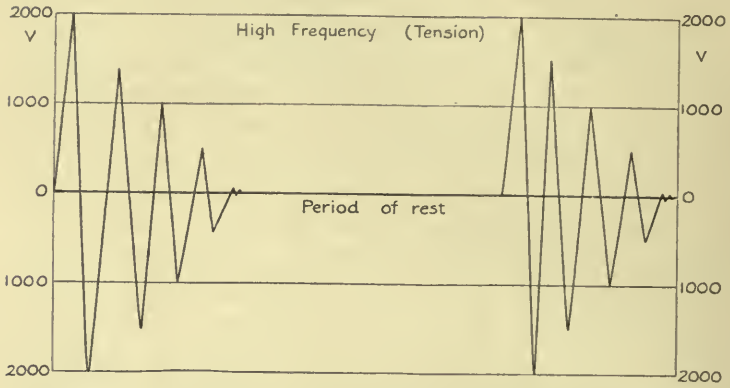

FIG. 10. Diagram of high-frequency oscillations of tension.

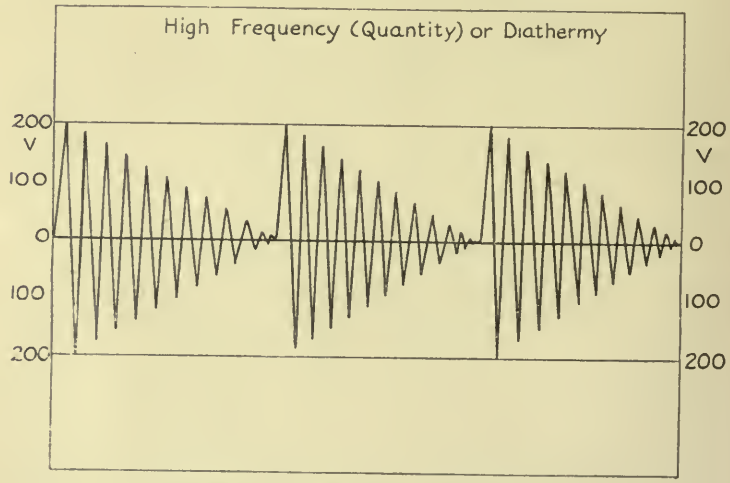

FIG. 11. Diagram of high-frequency oscillations of quantity (diathermy).

physiological and therapeutical difference between the two types is a very real one.

We have already seen, when discussing the action of the interrupted galvanic current, that a current, in order to

excite sensation or a muscular contraction, must have a certain minimal duration and a certain minimal strength: and that if the voltage of the current is largely increased, the minimal duration of an effective current may be reduced. We also found that the theory of the concentration of hydrogen ions at the make and break of a current affords a reasonable explanation of these phenomena. The same theory applies with equal force to H.F. currents. If the duration of a current of a certain voltage is below the minimal duration, no contraction will be excited. But if the voltage or strength of the current is greatly increased, a contraction will result with the former minimal duration. The reason for this is evident if we consider that time must be required for the movement, under the influence of the E.M.F., of the hydrogen ions from the electrostatic attraction of the oppositely charged ion. The higher the voltage of the current, the more rapid will this movement be, and consequently the less time will be required to overcome the electrostatic attraction of the oppositely charged ion. If we accept this theory, the atom, whilst in an ionic state, would have its chemical action inhibited by the electrostatic attraction of its oppositely charged associate, but on the application of a sufficient strength to overcome this attraction (hence the minimal strength required), it would be drawn forward away from this influence, and would immediately and automatically regain its chemical properties. By this theory, both the phenomena of minimal strength and of minimal duration are rationally explained.

With high-frequency currents of tension, the voltage may be so high that, in spite of the high frequency of the oscillations, sensation and even contraction may be excited; but with the high-frequency currents of quantity (diathermy) the voltage is so much lower and the frequency is so much higher that no sensation is experienced apart from that of heat.

The following measurements of wave length and frequency were taken from the Gaiffe and the Siemens instruments that I use in my private practice.

The observations were taken both with a Marconi and a Townsend wave-meter.

The Gaiffe Instrument.

At a weak strength (1) 120 metres = a frequency of approximately 2,500,000 oscillations.

Medium ,, (3) 155 metres = a frequency of approximately 2,000,000 oscillations.

Full ,, (9) 350 metres = a frequency of approximately 870,000 oscillations.

The Siemens Instrument.

At Zero current strength (0) 550 metres = a frequency of about 545,000 oscillations.

Medium ,, (5) 520 metres = a frequency of 580,000 oscillations.

Full ,, (10) 150 metres = a frequency of 2,000,000 oscillations.

With the Oscillothermex attached. (The H.F. attachment of the Siemens apparatus.)

At minimum strength 480 metres = a frequency of 625,000 oscillations.

At maximum strength 640 metres = a frequency of 470,000 oscillations.

The high-frequency currents obtained from another instrument with an Oudin resonator were of too long a wave length, and consequently too low a frequency, to give a satisfactory reading with the measuring instruments used in these observations.

Increasing the width of the spark gap raises the voltage of the H.F. discharge very quickly, and at the same time increases the wave length and decreases the frequency of the oscillations: it is important to remember this when employing instruments of which the spark gap is capable of adjustment. Thus, with the Watson diathermy machine, if the spark gap is suitably adjusted to yield the

maximum output through a high resistance, as from hand to hand; with the high resistance that the patient then offers no sensation will be experienced: but if a similar setting of the spark gap be utilized from passing the current through the much lower resistance offered by the transverse direction of the neck, a sensation of such strength may then be experienced by a patient under treatment for brachial neuritis as to make him leap from the chair. At my suggestion Messrs. Watson now fit a recording dial to show the width of the gap, so that it may be suitably adjusted before commencing treatment, and thus any unpleasant shocks from the use of too wide a gap for the part treated may be avoided. Also, by measuring the gap at which sensation is first experienced, a criterion of the hypersensibility, frequently present in cases of neuritis, can be obtained, and the improvement under treatment can in this way be gauged.

The frequency of oscillation required to abolish sensation and muscular contraction varies with the voltage of the current. In the so-called High-Frequency attachments designed for fitting to the diathermy apparatus, a different self inductance is employed, so that the frequency of the oscillations is reduced at the same time that the voltage is stepped up by the resonator. The therapeutic effects of these H.F. currents of tension (commonly called H.F. currents) are largely due to the stimulating counter-irritation which they excite; whereas the therapeutic effects of the H.F. currents of quantity (Diathermy Currents) are mainly due to the heating effects produced.

The H.F. currents of tension may be employed in the form of a breeze or *effluve*, sparks, or by means of vacuum tubes.

A very powerful electromagnetic field is induced in the coils of the Oudin resonator; this leads to molecular disintegration of the wire of which it is constructed, unless the wire employed is of a suitable kind (phosphor

bronze). Thus, if ordinary brass wire is employed, after a few weeks' use it will break and drop off the solenoid, and when a piece of this wire is examined it will be found to be so soft and friable that a length of about 6 inches will not have the tensile strength to support its own weight when held horizontally, but will break off at the point held.

The Grand Solénoïde consists of a wooden frame round which thick wire is spirally wound; it is so large in diameter that a patient is able to sit within its coils: oscillating currents are induced on the surface of the body of a patient so placed. This form of treatment is termed 'Auto-conduction'. The bulk and inconvenience of this instrument and the nervousness which the patient, not unnaturally, experiences, when encaged within its coils, have prevented its coming into general use in this country.

I have no personal experience of the Grand Solénoïde. It apparently originated from the early experiment of D'Arsonval, in which he found that a clinical thermometer, suspended within the coils of the small solenoid of his H.F. instrument, quickly indicated a rise of temperature when the instrument was functioning. This rise of temperature was due to the oscillating currents induced in the mercury of the thermometer, these currents producing a heating effect in accordance with Joule's Law: $I^2RT \times 0{\cdot}24$. The low resistance of the mercury permits a high intensity of current, and hence a considerable production of heat occurs. The same kind of action occurs when a patient is placed within the coils of the Grand Solénoïde.

Vasomotor changes are excited, especially in the cutaneous vessels of patients so situated, the patient's temperature is raised, and the usual sequel of increased respiratory exchanges, increased secretion of urine, and elimination of solids in the urine are claimed.

The most marked action attributed to this form of

treatment is the lowering of the blood pressure; this effect will be discussed when dealing with the treatment of hyper-arterial tension.

This method of auto-conduction is generally placed among the H.F. currents of quantity; but these currents differ from the usual forms of diathermic currents in being attracted to the surface of the body by the inductive action of the solenoid and do not pass deeply through the tissues, as is the case with the usual diathermy currents.

Diathermy Currents, or High-Frequency Currents of Quantity

A modern diathermy apparatus, with an oscillation frequency of one or two millions a second at a comparatively low voltage, enables currents of 3 amperes or more to be driven through the tissues of the body without producing any muscular contraction or tremor, and with no other sensation than that of heat. The frictional heat generated by millions of ions oscillating in this manner throughout the tissues is very considerable; and by its means the temperature of a whole limb, or of any organ of the body, may be raised to any desired extent; or the temperature of the whole body may be very considerably raised in the same manner. And, since the heat is generated within the tissues, the effect is incomparably greater than can be obtained by such means as hot baths or radiant heat, which merely heat the surface of the body. It is to this heat production that the therapeutic value of H.F. currents of quantity is mainly due: but it is possible that, as may be the case with galvanic currents, the bombardment of the undissociated molecules by the oscillating ions may have a stimulating effect on the tissue cells; and there is, moreover, reason to suppose that tissue drainage is accelerated, for it would otherwise be difficult to account for the rapid decrease in swelling that occurs in such a condition as a recently sprained ankle after the application of diathermy. In this con-

nexion, von Zeyneck (2) remarks : ' At the present time the question still remains, whether high-frequency currents produce any other effects on the organism (than those of heat) ? We are all forced to admit that these rapid vibrations have their own chemical action. The experiments made on albumen, on oxyhæmoglobin, on hæmatin, and on the enzymes, do not give any result, when the thermic action and the formation of sparks are excluded. Rumpf (3) has observed the same negative results.'

When attempting to raise the temperature of the whole body by diathermy, the rapidity with which the heat-regulating mechanism of the organism acts is well illustrated by the experiments of Furstenberg and Schemel (4) at the Brieger Institute. It was found, in these experiments on the diathermic heating of the stomach, that the temperature of that organ was not increased in proportion to the intensity of current employed. With a current of 300 milliamperes its temperature was raised about half a degree above normal. On increasing the current strength, however, to 3,000 milliamperes, the temperature of the stomach fell to only one-third of a degree above normal.

In agreement with the above results, I have found that, when passing a current of 2½ to 3 amperes through the body, after about ten minutes' treatment the temperature in the mouth rises about a degree, and is accompanied by a slight acceleration of the pulse rate : this rise, however, both in the temperature and the pulse rate declines again to normal after about ten minutes' further treatment, and then remains at normal, although a current of 3 amperes may be continuously administered for an hour.

Schittenhelm (5), employing the enormous current of 17 amperes, succeeded in raising the temperature of a healthy man 2 to 4 degrees centigrade in one and a half minutes, after which time dilatation of superficial vessels and sweating occurred, and no further rise of temperature

could be induced. Prolonging the treatment considerably caused a fatigue of the peripheral vessels and a diminution in the secretion of sweat. Stein (6) also records that the temperature of the body can be raised about 5 degrees in ten minutes.

The employment of the high intensities of current necessary for the production of such rises of temperature has not as yet been generally adopted in electrotherapy, and its adoption would not be unattended with risk.

Although the general rise of temperature in clinical diathermy is a small one, the therapeutic effect on the general system, especially if the treatment be a prolonged one, is not necessarily of little value. The dilatation of the peripheral vessels, the increased perspiration—a very varying factor in my experience—the increased elimination of solids in the urine, and the other results which follow from a rise in the temperature, may be reasonably supposed to aid in the elimination of toxins and to have a favourable influence on the treatment.

When we turn to the local effects of diathermy, the results are far more definite and less hypothetical. By means of the diathermic current, the heart, the lungs, the kidneys, the ureters, the bladder, the ovaries, every organ of the body, or a limb throughout its whole length, may be heated to any desired extent.

The effect of the heat generated within the tissues is to dilate the blood vessels, thus relaxing spasm and tension and consequently relieving pain.

This relief of pain constitutes by far the most valuable property of the diathermic currents. Occasionally a temporary increase of pain may be experienced during the administration of the current; this is especially found to occur when the current is applied too strongly at first; it would appear to be due to a temporary congestion of the tissues arising from the increased blood supply before the surrounding parts have been relaxed by the heat. This exacerbation of pain is only temporary

and immediately ceases when the current is reduced in strength or is cut off; it is usually of good omen, for the subsequent relief is generally very marked in these cases. As a few instances of the effect of the treatment in the relief of pain we may quote the following. Dysmenorrhœa may often be prevented by the application of the current to the ovarian region two or three days before the expected period, or the pain may be immediately relieved during the period by a similar application. A current of about 3 amperes is passed through the abdomen in the ovarian region for about fifteen minutes, and little or no exposure of the patient is necessitated. A renal calculus, from the irritation that it excites, may be gripped by the spasmodic contracture of the ureter, so that its passage is arrested, and a dull aching pain is thus set up: this spasm may be relieved by diathermy, and the passage of the calculus will be facilitated, but then the acute pain of renal colic will temporarily replace the dull ache. The acute pain of neuritis, lumbago, etc., can usually be immediately relieved, and often speedily cured by diathermy applied in the proper manner. Contrasting its action in such cases with the action of the continuous current, my experience is that diathermy should be selected in recent and acute cases: but that in chronic and in less acute cases the continuous current is to be preferred. In many cases the two treatments may be advantageously combined.

The surgical application of diathermy is useful in a variety of conditions. At first sight, the destruction of tissue by this method is apt to be confounded with its destruction by the actual cautery. There is this most important and fundamental difference; that, whereas with the cautery there is actual burning or incineration of the tissues, with the consequent danger of immediate or secondary hæmorrhage, in diathermic destruction the tissues are not burnt, but are coagulated, and in this way the blood vessels are firmly plugged, so there is a complete absence of all hæmorrhage at the operation,

and there is subsequently no danger of secondary hæmorrhage. The tongue, for instance, can be removed by this method without the loss of any blood. The depth to which the coagulation necrosis extends can be regulated both by the strength of the current and the length of time during which it is applied. As a rule, if a superficial action is aimed at, a strong current is administered for a short time, and, if a deeper effect is wished for, a weaker current is employed for a longer time.

Diathermy admits of the destruction of villous tumours of the bladder *per urethram*. Most urinary surgeons have adopted this method for the destruction of these tumours, and it is regarded by many as the only justifiable procedure.

Hæmorrhoids can be advantageously treated by diathermy, as in the milder forms of the trouble no pain and no inconvenience is suffered by the patient ; and, in the more severe forms, only a local anæsthetic is required.

Minor blemishes of the skin, such as warts, nævi, moles, etc., may be removed, almost painlessly, and with great accuracy and delicacy, by a method, termed ' Indirect Surgical Diathermy ', which I introduced some years ago. The patient, when undergoing this treatment, lies upon a ' condenser couch ', the metal plates of which are connected with one terminal of the apparatus, and holds in his hands an electrode connected with the other terminal ; in this manner he is charged from the diathermy apparatus with about 500 milliamperes, which he appreciates, if he feels anything at all, as a gentle warmth at his wrists.

A pointed metal instrument, with no wires attached to it, is held in the hand of the operator and applied to the part to be destroyed. The current with which the patient is charged is attracted to the base of the growth, and inductively attracts to the surface of the growth a similar current from the capacity of the operator. The current oscillates in this way over a million times a second, so that the destructive process operates almost simultaneously on the surface and the base of the growth. The base of

the growth is often seen actually to light up during process. I have recently introduced a modification of this process under the name of diathermic massage: in this method the tips of the operator's fingers are substituted for the metal instrument, and there is consequently not the same degree of concentration of current and heat. By gently stroking a painful superficial area in this way a sensation of warmth is imparted to the part, which is very soothing and has been found to be of considerable benefit in the treatment of acute facial neuralgia.

The administration of diathermy, both in its medical and surgical forms, requires more skill and experience than any other form of electrical treatment.

In the application of medical diathermy, the position of the pads and the direction of the current are of the greatest importance. In brachial neuritis, for instance, the seat of the trouble is, in my experience, most commonly situated where the nerves pass through the intervertebral foramina of the cervical spine: and, in such a case, to apply the pads to the points to which the pain is referred would be an utterly useless procedure. Again, when the current, as is often the case, has to be pushed to nearly the limits of safety, its administration should certainly not be entrusted to the hands of unqualified persons. One of the fascinations to the experienced electrotherapist of this form of treatment is the frequent discovery of new methods of its application.

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CHAPTER IV

THE INFLUENCE MACHINE AND STATIC ELECTRICITY

The Therapeutic Action of the Currents derived therefrom

THE frictional machines employed in the eighteenth century for generating static electricity proved unsatisfactory in consequence of their small output, their susceptibility to the dampness of the atmosphere, and the attention which their rubbers required; they have consequently been entirely superseded in therapeutic work by the influence machine.

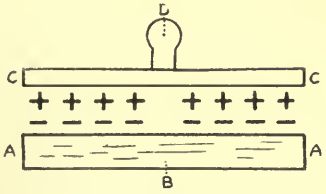

FIG. 12. The electrophorus.

The principle of the influence machine was first demonstrated by Volta, in 1775, by means of his electrophorus. In order to understand the action of an influence machine it is best to make a preliminary study of this simple apparatus.

The electrophorus (Fig. 12) consists of a metal base A, containing a flat circular disk B, composed of resin, sulphur, ebonite, or other non-conducting material, and a circular metal disk C, attached to an insulated handle of glass or vulcanite D.

When the resin disk B is rubbed with cat's fur, it becomes charged with negative electricity on its surface. The metal disk C, when applied to the resin, becomes inductively

acted upon by the negative charge on the surface of the resin, with the result that the electrons, or negative charge of the metal disk, are repelled to its upper surface, while a positive charge remains on its surface in contact with the resin. On touching the upper surface of the metal disk with the finger, the electrons which have been repelled to its surface are discharged to earth, and the disk C then becomes positively charged.

A Leyden jar or other capacity can be then charged positively by contact with the metal disk, and the disk can be recharged repeatedly by again bringing it into contact with the resin and retouching it with the finger; this process can be repeated indefinitely without recharging the resin, provided that the atmosphere is sufficiently dry and free from dust to prevent the initial charge from leaking away.

The influence machine mechanically performs the function of the electrophorus. The first type of this apparatus was introduced by C. F. Varley in 1860, five years later it was followed by the machines of Holtz and Toepler, and more recently these machines were displaced in general use by the well-known Wimshurst machines.

The Wimshurst machines are of two types: one type is provided with sectors of tinfoil near its circumference, and is self-exciting; the other type has no sectors, and has to be excited by friction from the finger or other source, or by receiving a charge from another machine.

For medical purposes the sectorless type is preferable, as it is less likely to reverse the polarity of its collecting brushes whilst it is in operation. A Wimshurst machine consists of 2, 4, 6, or more disks of glass, or ebonite, arranged in pairs. In each pair one disk revolves clockwise, the other in the opposite direction. Its mode of operation may be explained as follows:

Let the anterior and posterior disk of the ordinary Wimshurst be represented for simplicity of explanation by

an external and an internal cylinder respectively (Fig. 13). On applying a dry finger in contact with the external ebonite cylinder at A, opposite the brush B, a positive charge is excited in the external cylinder at the point of contact; the finger may then be taken away: by the inductive action of this positive charge, a negative charge is excited in the brush B, which is in contact with the internal cylinder and

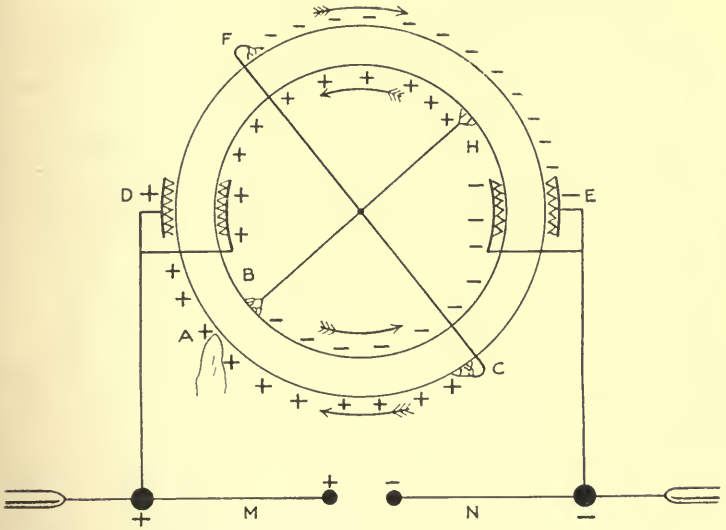

FIG. 13. Diagram to illustrate action of an influence machine.

conveys to it this negative charge. The internal cylinder revolving in an anti-clockwise direction brings this negative charge towards the brush C, in contact with the external cylinder; on arriving at this point the negative charge on the internal cylinder induces a positive charge in the brush C, which is communicated to the external cylinder in contact with it, and is carried by the external cylinder, revolving in a clockwise direction, to the collecting combs D. The internal cylinder, continuing its rotation, brings its negative charge to the collecting combs E. The upper halves of the plates receive a charge

of opposite polarity to their lower halves in the following manner. When the brush C receives its positive charge, a negative charge is repelled along the metal rod CF to the brush F, which thus becomes negatively charged and imparts a charge of similar polarity to the portion of the outer plate in contact with it. This negative charge is then conveyed to the collecting combs E.

In a similar manner, the brush B having a negative charge, a positive charge will be repelled along the rod BH and will collect on the brush H, from which it will be communicated to the part of the internal cylinder in contact with it, and will thence be conveyed to the collecting combs D. Thus the combs D will collect the positive electricity from the upper halves of the internal and from the lower halves of the external cylinders; whilst the collecting combs E will collect the negative electricity from the upper halves of the external and the lower halves of the internal cylinders. These respective charges will be conveyed to the discharging rods M and N.

On the Choice of a Static Machine

The following are the requirements of a good static machine:

1. The machine should not require too great a force to drive it. This point is not of so much importance as formerly, when the machine was driven by hand. Nowadays, no electrotherapist would contemplate driving the machine otherwise than by mechanical or electrical power, and the power of the driving motor can be easily regulated to meet the requirements of the apparatus.

2. The machine should be as little as possible affected by damp and weather conditions, so that it may be readily excited and yield its maximum output at all times. This is a self-evident proposition which it is easier to lay down than to accomplish completely. It is a point which will be dealt with when considering the maintenance of the apparatus.

3. The machine should be capable of yielding a current of very high potential. Provided that the insulating material used is efficient, the potential obtainable depends solely upon the diameter of the plates; the space between the innermost projection of the collecting combs may be regarded as the cross-section of the insulating material. It is evident that a potential cannot be obtained greater than that required to yield a spark across a gap equal to the interval between the innermost projection of the collecting combs. In actual practice a spark length should be obtainable, under ordinary working conditions, equal to one-third the diameter of the plates.

4. The output in current should be as great as possible, and should admit of ready and exact regulation. The output depends on the number of the plates, their proximity to one another, and the rate at which they revolve. (The output, however, is not in direct proportion to the increase of these factors.) It consequently follows, if a high milliamperage is to be obtained, that the plates should be constructed of a material permitting a high rate of revolution without disintegration occurring under the influence of centrifugal force at high speeds.

The regulation of the output can be effected in two ways, namely, either by adjusting the speed of the motor, or by means of a device for leaking away the current accumulating at the collecting combs, as in the ingenious arrangement fitted to the Baker machines.

5. The polarity of the apparatus should not change during its operation. This is accomplished by keeping the machine as dry as possible, and by avoiding the use of machines furnished with sectors.

6. The apparatus should be robustly constructed in all its parts, and the plates should be of a material which is not liable to warp, or deteriorate on exposure to light. The whole apparatus should be enclosed in a dust, and, as far as possible, a damp-proof glass case.

The Wimshurst machine with sectorless plates is

chiefly used on the Continent and is highly spoken of by French workers ; it has, however, one or two serious faults. It is perhaps due to their use of inefficient machines that the French are unable to claim the same pre-eminence in the use of static electricity that they possess in other forms of electrotherapy. They appear from their writings to under-rate the value of the Morton wave current, the most valuable of the static methods, for the effective administration of which a machine of the American type is indispensable.

Apart from the tendency of the ebonite plates of the Wimshurst machines to warp and get out of truth, they are liable to sulphate when exposed to a bright light and so lose some of their non-conducting properties, thereby becoming much less efficient. This latter fault can, to a great extent, be remedied by keeping the apparatus covered by a dark cloth when not in use ; and the sulphur deposit, when formed, may be removed by rubbing the plates with a solution of ammonia or paraffin. The Wimshurst does not necessarily require a glass case, but such a fitting is of use in keeping dust away.

In actual practice it is the difficulty of obtaining the slow, heavy, pounding spark that renders the Wimshurst unsuitable for the Morton wave current.

To obtain a satisfactory apparatus for all the forms of static treatment, recourse must be made to the American machines. As the result of the work of the late Dr. W. J. Morton, of New York, and in more recent years of the writings of Dr. William Benham Snow, also of New York, static treatment has developed in the United States to a far higher degree of efficiency than in any other country.

In Great Britain, Dr. F. Howard Humphris, who learnt the therapeutic value of the static machine during his residence in America, has succeeded, in spite of much opposition from those who neither possessed nor had used an efficient apparatus, in obtaining for static treat-

ment in this country an established position among the recognized therapeutic methods.

The American machines are of two main types, the Van Houten and Ten Broeck glass plate machine (212 East 23rd Street, New York City), and the Baker static machine manufactured by the Baker Electric Co., 438 Asylum Street, Hartford, Conn. Both these types are of the sectorless variety and have therefore to be provided with small self-exciting machines to impart to them the initial charge. The glass plates of the Van Houten machines cannot be revolved at a high rate of speed; their milliamperage output is therefore small unless a large number of plates are employed. On the other hand they will run very slowly and will yield the slow, heavy, regular, pounding spark of high voltage, which is so essential for the proper administration of the Morton wave current ; these are then the machines *par excellence* for this method. Glass certainly appears to be the best dielectric material for obtaining this high voltage spark at low speed.

In the Baker type of machine the revolving plates are made of sheets of paper compressed and cemented together under heavy hydraulic pressure. Manufactured in this way they ring like steel when struck, and their cohesion is such that they can be revolved at very high speed without fear of disintegration. The output in milliamperes is very satisfactory, and it can be leaked away, when a smaller output is required, from the collecting combs back to the field combs by a very ingenious arrangement of a lever operated by hand, a patent of the Baker Company. Between the revolving plates are a pair of stationary glass plates, between each pair of which, near their circumference, two strips of tin foil are diagonally inserted. To one of these strips of tin foil an initial charge has to be conveyed from an exciting machine before the apparatus will function.

The output of these machines is far greater than that from those furnished with glass plates ; they are therefore

more suitable for the static charge, static breeze, and vacuum tube treatments. Moreover, with practice the excess of current can be so readily and easily leaked away that they are quite suitable for administering the Morton wave current.

An efficient machine of this type for either hospital or private work is one fitted with eight revolving and eight stationary plates of 36 inches in diameter. This is described as an 8–16 type. I have had two such machines for the past 7 years in daily use, one in the hospital, the other in my private practice, with most satisfactory results. The chief drawback to the general adoption of these machines is their high cost; before the war a completely equipped Baker machine, such as is above described, cost £200 delivered and erected in this country. This price would probably be more than trebled at the present time.

The Care of the Static Machine

To keep a static machine in good working order, the case should be made as closely fitting as possible to exclude dust and damp. Within the case should be placed dishes containing sulphuric acid, or bags containing quicklime. In my own practice I employ three 12 inch by 10 inch photographic developing dishes containing sulphuric acid; and also, within the same case, two boxes constructed of wooden battens, spaced about half an inch apart with lids similarly constructed, the interior of the boxes being lined with a close mesh gauze to prevent the dispersion of the lime dust. The boxes are one-third filled with about 10 lb. of quicklime. Care must be taken to place only sufficient acid in the dishes to cover the bottom of the vessels to a depth of a quarter or half an inch, or otherwise the acid, as it absorbs the moisture, will in time overflow the dish; in the same way, the lime, if it is too closely packed, will, on absorbing the moisture, swell and burst through the gauze lining of the boxes. An anthracite stove con-

tinually burning in the static room materially assists in keeping the machine in good condition.

The static machine should not be placed against or near the wall, nor should any furniture be placed near it. If possible it is a great advantage to place the static machine in a room by itself.

The insulated platform should be strongly constructed of well-seasoned, hard wood; its dimensions should be about 42 inches long and about 26 inches in width; round the edge a rim should be attached to prevent the treatment chair from slipping off, and its corners should be well rounded. It should be mounted on six vulcanite or glass legs, 4 to 5 inches in circumference and 9 to 10 inches in length. The insulation of the platform is much improved by placing the legs on glass insulators such as are sold for insulating pianos.

At least two Leyden jars should be provided; the inner coatings of these are attached to the discharging rods, and their outer coatings are earthed, or are attached to the patient according to the form of treatment to be administered. It is a good plan to have several Leyden jars of different sizes.

The treatment chair should be constructed of cane, or of well-seasoned wood; it should be free from nails and metal of all kinds. It is difficult to be certain that no nails or small brads have been used in the construction of the cane chairs until a static bath treatment has been given, when the presence of any metal will be readily detected. The back of the chair should be made adjustable, so that it can be raised or lowered, or be entirely removed. A detachable leg piece should be fitted to allow of the chair being used as a couch for vaginal or prostatic treatments.

The Determination of the Polarity of the Collectors

The positive charge appears on the collecting combs as a number of bright blue points (positive points);

if the discharging balls are slightly separated, the sparks will be seen to travel by a nearly straight line for about an inch on the positive side, and they will be of a bright blue colour. If a dry stick is brought near the positively charged rod or ball, only a short stream of sparks will be obtained.

On the negative side of the machine, at the collecting combs, the charge appears as a brush or aigrette; on separating the balls the sparks issuing from the negatively charged ball at once diverge and are of a pale violet colour. From a dry stick approached to the negative side a long aigrette or brush discharge is obtained.

Connexions to Earth

Two long brass chains should be provided; one of these should be placed on the right and the other on the left of the machine. Each of them should be led to earth by a separate path; one earth connexion may be conveniently made through the water pipes, the other should lead by a wire to a plate buried in the earth. An earth connexion should not be made to, or near to, a gas pipe.

The Therapeutic Methods obtainable from the Static Machine

The therapeutic effects of static electricity become manifest when the charge ceases to be static and becomes current electricity. To speak of static currents is to make use of a contradiction in terms, for of course when the static charge is converted into a current it ceases to be static electricity or electricity at rest.

The treatments derived from the static machine may be either general or local in their action.

The Static Charge (synonyms: Static Insulation, the Static Bath, Simple Charging, Static or General Electrification).

This form of treatment has a general or constitutional effect.

Arrangement of Apparatus and Patient. The positive side of the machine is earthed, the discharging balls are widely separated, and the negative side is connected with the platform by means of a hooked brass rod, known as the Shepherd's Crook. The patient is seated on the platform in a reclining chair, and care should be taken to place him in a comfortable position with the limbs relaxed and the head supported by cushions.

Method of Administration. The machine, previously charged, should not be started until the patient is comfortably seated. The full output of the apparatus is

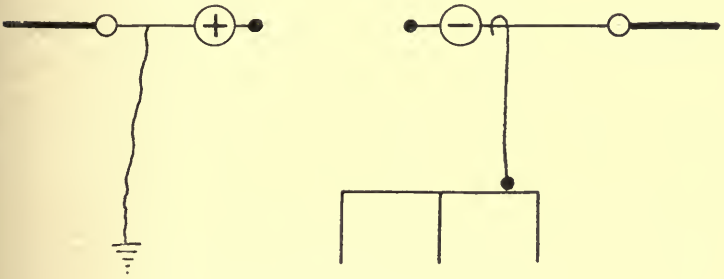

FIG. 14. Diagram of static charge.

utilized. The operator should not approach too near the platform, or he will draw sparks from the patient. The patient should be instructed not to talk, to keep himself as quiet as possible during the treatment, and to compose himself for sleep.

The Therapeutical Effects of the Static Charge

Let us first note what we observe whilst the patient is undergoing this treatment.

The most obvious phenomenon is that the patient's hair 'stands on end'. This is due to the hair acting as a separate capacity, and, its extremities being free to move, it is repelled from the body, which has a similar electrical charge, in accordance with the elementary electrical rule that bodies having a similar electrical

charge are repelled from one another. Not only the hairs on the head but all the hairs covering the skin can be seen to be repelled in a similar way. If the patient extends his arm and fingers, the current will be seen leaking away from his fingers in the form of a brush discharge. The patient usually describes his sensations as of a particularly soothing nature, and he will often drop off to sleep, even though the complaint for which he is undergoing treatment may be sleeplessness. A very gentle tingling sensation is experienced, described by some patients as a feeling of being covered with cobwebs.

The explanation of these phenomena is that the patient is charged all over with negative electricity; this charge is inductively attracted to the surface of his body by the walls, furniture, and other surroundings. The charge is prevented from discharging by the insulating or dielectric action of the air. The patient may therefore be likened to the inner coating of a Leyden jar, of which the air takes the place of the glass dielectric, the walls, furniture, etc., of the room forming its outer coating. The air, however, is not a perfect insulator or dielectric, owing to the dust and moisture which it holds in suspension; consequently a considerable amount of the charge, in the form of current electricity, is continually leaking away from the patient to the neighbouring objects in the room.

It is evident from these phenomena that the skin all over the body is being continually stimulated by the high potential charge, which is either gradually leaking away, or is maintained in a state of electrical tension on the skin surface by neighbouring charges of different polarity, acting inductively through the dielectric of the air.

Renton Elliott[1] has shown that stimulation of afferent nerves leads to an increase in the output of adrenalin from the suprarenal glands, and consequently to an increase in the blood pressure. There is much evidence

[1] *Journal Physiol.*, **44**, 374–409.

to show that the raising of the blood pressure, due to the stimulation of the afferent nerves of the skin, is the primary and main effect of the static charge. For instance, it has been recognized for many years that this form of treatment is especially indicated for cases of neurasthenia with low blood pressure, that it is also indicated as a general stimulant or tonic when the patient is exhausted by prolonged pain, anxiety, or overwork, or where sleeplessness has resulted from either of these causes. In short, the treatment holds out hopes of benefit when the symptoms are such as are associated with low blood pressure. On the other hand, its use is contra-indicated when the blood pressure is raised; in fact, it ought never to be applied where there is marked hypertension. I was once treating, for chronic rheumatism of one of his knee joints, an old farmer of the apoplectic appearance usually regarded as typical of the national John Bull and clearly indicative of arterial hypertension. The joint was improving with galvanism, when one day, on stepping out of his trap, he unfortunately twisted the affected knee, and to remove the resulting effusion I gave him the Static Morton Wave current. He, soon after the commencement of the treatment, began to complain of 'fuzziness' in the head. On his next visit, he brought a message from his wife to the effect that she did not so much mind her husband being 'groggy' in the knees, but she did not want to have him 'cracky' in the head as well, so she would not like him to have any more of the treatment which he had last time. This untoward occurrence was clearly the result of an increased blood pressure, and, being an undesired and unlooked-for effect, was consequently more convincing than scores of successful treatments specially designed to prove the value of some particular method. Bordier[1] records that as the result of the static bath treatment 'the arterial tension is increased, all experimentors are agreed upon that point.

[1] Bordier, *Précis d'Électrothérapie*, second edition, 1902.

An experiment by Charcot clearly showed this effect of the bath ; the blood ceasing to escape from a man who was being bled, he was given a charge, when the blood recommenced to flow.'

Bordier also calls attention to the acceleration of the pulse rate, and quotes Truchot [1] to the effect that the acceleration may be as much as 20 per cent. The return to the normal pulse rate is said not to take place till a week has elapsed after the cessation of the treatment. So far as my own observations go, the immediate rise of blood pressure after the treatment is not always very marked ; but I have found that a later rise in the arterial tension usually synchronizes with an improvement in the general symptoms.

The following are the other effects claimed from the application of the static charge : a rise in the general temperature of the body, an increase in the excretion of urea, an increase in the dynamo-metric force, and an increase in the secretion of the sweat glands. With the exception, perhaps, of the last named, which I have usually found to be most noticeable during a first treatment, and which may be reasonably attributed to a fear of the unknown, all these effects can be attributed to an increased blood pressure.

The special indications for this form of treatment are neurasthenia when associated with low arterial tension ; sleeplessness, when arising from overwork or worry or other exhausting causes ; headaches, when arising from similar causes.

There is a variety of the static charge treatment in which the discharging balls are approximated, and a spark allowed to discharge across them ; it is termed ' Potential Alternation ', or ' Interrupted Electrification '. It need only be mentioned to be condemned, as it only irritates and disturbs the patient, and can serve no useful purpose.

[1] *Archives d'Électricité Médicale*, 1894, p. 49.

The Dosage or Quantity of Electricity administered to the Patient

At first sight the static machine is a most alarming instrument, and the patient, in reply to the question, which, at his first visit, he usually asks in reference to the voltage of the apparatus, does not derive much reassurance from the kind of reply often given 'Several hundred thousand volts', or even from the still more inaccurate answer 'A million volts'.

As a matter of fact the static machine is one of the safest instruments in the armamentarium of the electrotherapist. The maximum output from a good French machine is given as from one-tenth to one milliampere, and the maximum output from a modern Baker machine is from one to two milliamperes. As in all other forms of electrical treatment, it is the density of the current administered to the patient that must be considered, and this depends upon

$$\text{Superficial Density} = \frac{\text{Quantity of Electricity}}{\text{Surface}} \text{ or } D = \frac{Q}{S}.$$

Even in a direct short to earth the amount of current passing would be extremely small; but as the patient in all static treatments is placed on an insulated platform, the amount of charge which he can receive is consequently limited by his capacity, which varies with his surface area and with the voltage at which he is charged, but in any case gives rise to a very small amount of current. The result is that the density of the charge on any square centimetre of the patient is extremely small, so minute is it that a new electrical term, the Franklin, has been introduced by Benoist to express it. A franklin equals 1/3,000,000,000 of a coulomb; it is the quantity of electricity which repels with the force of one dyne (about a milligram weight) an equal quantity of electricity of the same polarity at a distance of one centimetre.

Benoist has designed an electrodensimeter, an instrument which registers in franklins the density of the

static charge on one superficial square centimetre of the body ; in all cases the amount is found to be extremely small, perhaps ten to fifteen franklins. Such calculations show the minuteness of the electrical density of the static charge and serve to explain the absolute safety of this treatment.

The Static Breeze

If an earthed metallic electrode is brought near a patient receiving a static charge on the insulated platform, the

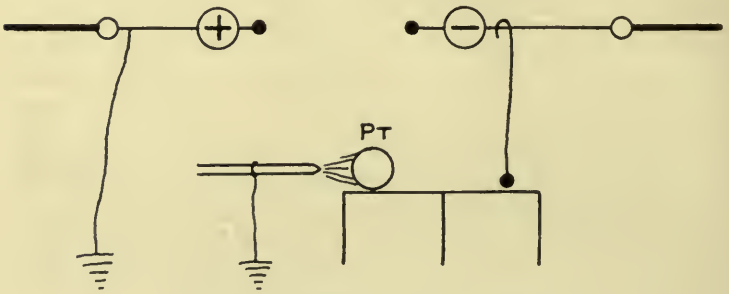

FIG. 15. Diagram of static breeze.

patient's charge will immediately discharge to earth in a powerful disruptive spark ; this is known as the static spark, and will be described later. If, however, in place of a good conductor, a dry stick or other body of high electrical resistance is used, the charge will pass gradually to the conductor from the patient in the form of a convective brush or breeze ; this is known as the static breeze. If the patient has a positive charge, the breeze will only be an inch or two in length, and will be very prickly or stinging in character. With a negatively charged patient, and this is the polarity used in this treatment, the discharge will be in the form of a bluish brush, and by using a suitable instrument a breeze 12 inches in length may be readily obtained. Various forms of electrodes have been designed for this purpose, a well-seasoned ash walking-stick answers very well, but for a smooth convective brush

discharge the best instrument is the De Kraft pencil. This consists of a vulcanite fibre tube about 18 inches long and three-quarters of an inch in diameter, tightly packed with asbestos string or powder, and terminating at the extremity towards the patient in a blunt brass point with an angle of about 90 degrees; the other end of the instrument is fitted with a brass cap and ring for attachment to the grounding chain. An instrument constructed in this way gives a very soft discharge, which when the rod is held some distance from the patient gives him the sensation of a cool breeze; if the instrument is approached within one or two inches of the patient, the sensation becomes of a more tingling or burning character. Usually the American machines are sold fitted with a variety of maple sticks, some with points for a gentle convective breeze, others terminating in rounded knobs for exciting a more disruptive and stimulating discharge. These sticks are usually provided with a sliding ring for the attachment of the grounding chain. When using electrodes of this pattern, the operator should remember to hold the stick with the ring between his hand and the patient. A head breeze is obtained by fixing at a suitable distance above the patient's head a circular metal disk, from which a number of fine metal points project, and by connecting this disk to earth through a support of suitable resistance.

The blue colour of the static breeze is due to the electrical illumination of the dust particles in the air.

Boudet, of Paris,[1] has shown that the area of surface affected by the breeze is one and a half times the distance separating the point of the electrode from the surface to which it is applied.

Much confusion is liable to arise in the use of the terms positive and negative breeze. A negative breeze is administerèd when the patient is positively charged, for he then attracts a negative current from earth; on the other hand, if the patient is negatively charged, the breeze

[1] *Électricité Médicale*, p. 124.

obtained is termed the positive breeze. The breeze in either case is conveyed by the ionization of the particles of moisture and dust in the air. If a piece of pole-testing paper (turning violet under the negative pole) be placed on the positively charged platform of the static machine, and the point of an earthed electrode be brought in contact with it for a few minutes, a pink point will develop on the paper showing the negative current ; with the platform negatively charged this result will not be obtained. But on placing the paper on the ground and bringing into contact with it the point of an electrode connected with the negatively charged platform the violet colour will be obtained.

The brush discharge is conveyed by the ions in the air, the positive and negative ions travelling from earth to the patient or from the patient to earth, according to the polarity of his charge.

The point of the grounded electrode may be regarded as the small active, and the patient as the large indifferent electrode ; and as, in unipolar galvanism, we only consider the current coming from the small active electrode, and disregard the current of far lower density coming from the large indifferent electrode, so in the static breeze we need only consider the current, of opposite polarity to the charge, coming from earth to the patient through the point of the electrode, as the active current ; and thus we speak of the negative breeze when the patient is positively charged, and the positive breeze when the patient has a negative charge.

The Therapeutic Action of the Static Breeze

It is evident that the static breeze, when it is administered in its disruptive form, either from a blunt electrode, or from a pointed electrode held near the patient, thus exciting a pricking and stinging sensation, must have a considerable effect as a counter-irritant. In this way it is of some service in the treatment of the acute pain of

neuritis, though the relief which it affords in such cases is only of a temporary character.

The soft convective breeze communicates to the patient the sensation of a cold draught of air blowing on the part under treatment ; this breeze has been shown by French workers to have a certain cooling effect on the skin, and they state that they have found its effect persists for some time after the cessation of the treatment.

There is a considerable amount of ozone formed by the ionization of the air by the static breeze, and this may have a certain germicidal effect when the breeze is applied to wounds and ulcers, apart from its beneficial influence in stimulating an increased blood supply in these conditions.

Applied as a spinal breeze, especially in the region of the last ribs, this method is certainly of value in combination with the static charge for the treatment of neurasthenia associated with low blood pressure. In such cases the breeze should be as disruptive as can be readily tolerated by the patient ; it should be applied for about five to ten minutes ; and the treatment should be concluded with a simple static charge, the patient reclining comfortably on the chair for fifteen or twenty minutes.

As a head breeze, this treatment is certainly of considerable value in sleeplessness and headaches, the result of overwork or exhaustion.

This method has been used with benefit in cases of chronic eczema and alopecia, but in such cases the ultra-violet radiation from the tungsten arc gives far better results.

Warts and similar small growths may be removed by the concentration of a static breeze of short length, but here again this treatment is far less efficient than the indirect method of diathermic coagulation.

Sparks from the Static Machine

The so-called Static Sparks may be administered either (1) directly from the static machine with the exciting

electrode connected to the negative or the positive discharging rod, usually the former, the other discharging rod being grounded; these are termed direct sparks. Or (2) the sparks may be administered with the patient on the platform, as in the static bath or breeze, and the platform connected with one of the discharging rods, usually the negative, the other discharging rod being earthed. The operator then draws off sparks from the patient by swinging, towards the part to be treated, an electrode, terminating in a metal knob connected to earth by a grounding chain, and held by an insulated handle. These are called indirect sparks. With modern machines the direct sparks are rarely used, as their effects are too severe.

Physiological Effects of Static Sparks

Short weak sparks excite a pricking sensation, but, as the potential of the machine's output is increased, this pricking sensation gives place to one of shock.

The main effects of static sparks are two in number: (1) local vasomotor changes; (2) the excitation of muscular and possibly also tissue or cellular contraction.

After a powerful static spark has been administered to the œdematous skin of a patient, there is at first a small circular depression, resembling a vaccination scar, much whiter than the surrounding skin; this pale anæmic area quickly gives place to a red and hyperæmic circle, which persists for some hours. If a shower of sparks is continued for some time on one spot, a blister with destruction of the superficial tissues will result.

Bordier has shown that the vasomotor effects of positive sparks are greater than those from the negative ones; he has also pointed out that, in certain conditions such as exophthalmic goitre, dermatographic lines may be drawn by a series of sparks.

The most important effects of static sparks are due to the muscular contraction they excite. Bordier has

shown that direct sparks excite contractions giving myographic tracings which correspond in character with those obtained from the interrupted galvanic current, that is to say, with the negative spark a steep, sharply bent curve, with rapid rise and fall, is obtained ; and with the positive spark the tracing shows a blunter, less steep curve with more gradual rise and fall. The polarity of the treatment is therefore of some importance.

When using the indirect spark, the polarity of the exciting grounded electrode is the opposite of the patient's charge, as we have seen was the case in the static breeze treatment, from which the sparking method only differs in the use of a good in the place of a bad conductor. Since in the indirect method the negative charge is usually given, the spark obtained would be a positive one.

At first sight this might appear to be the less efficient form ; but it must be remembered that, whereas the direct spark would correspond to the current of make in galvanism, the indirect spark would correspond to the current of break.

Now the work, already referred to, of Cardot and Laugier[1] and the experiments of Bourguignon[2] show that at the make of the current it is the negative pole which alone is active, and at the break of the current it is the positive pole only which excites contraction. We thus have an explanation why it is that with the direct spark the negative, and with the indirect spark the positive, is found to be the more effective polarity.

The degree of muscular contraction obtained from a static spark is directly proportionate to the square of the spark (Bordier).

Method of Administration of the Static Spark

It should be borne in mind that this treatment is an unpleasant one, and it should not be the method of choice,

[1] *Journal de Physiologie et de Pathologie générale*, 1912.

[2] *Revue Neurologique*, April 30, 1914.

if the desired result can be obtained by less painful means.

Much may be done to modify the violence of the spark. Its effect varies with the form of the exciting electrode ; with a pointed electrode, a pricking or stinging sensation is experienced ; with a large rounded metal knob at the end of the electrode, the sensation is more of a heavy pounding shock.

This difference is due to the larger capacity of the bigger electrode. The length, and consequently the strength, of the spark can be regulated by approximating the discharging balls of the apparatus, for the length of the patient's spark cannot exceed the distance between the discharging balls. The strength of the spark may be reduced by the operator placing a foot on the platform and so leaking away some of the current, or a chair may be placed near the platform with a similar object.

An adjustable spark gap may be placed between the exciting electrode and its attachment to earth; thus by lengthening or decreasing this gap, the strength of the patient's spark may be correspondingly increased or diminished.

The sparks should be administered by swinging the electrode towards the patient with a regular rhythm, so that he may know when to expect the shock, and care should be taken so that only one spark occurs at each swing of the electrode, the double or treble sparks which sometimes pass are far more painful than the single ones.

The Therapeutic Effects of the Static Sparks

The vasomotor action of the static spark may be entirely neglected ; if a hyperæmia of the skin is required for the treatment of an atrophic condition, such as alopecia areata, the desired effect can be far more readily and conveniently obtained by the application of ultra-violet radia-

tion from the tungsten arc. By the excitation of muscular and tissue contraction static sparks exercise a decompressor effect on swollen and engorged tissues. By this means acutely painful conditions are often immediately relieved, especially where the pain is confined to a small area. In the treatment of tennis elbow and rider's sprain I have found static sparks of great value. Sciatica, especially when the pain is very acute, is often much relieved by this method, but I have not found it produce any lasting improvement.

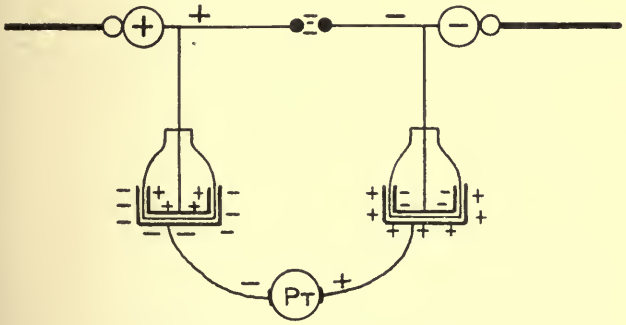

FIG. 16. The static induced current.

The Static Induced Current

The static induced current was introduced by Dr. W. J. Morton in 1881. It is generally regarded as a form of high-frequency current, and it has been claimed that it was the first form of that current to be discovered.

In this treatment the patient is not insulated, but may be treated on any ordinary chair or couch. Two Leyden jars are connected by their inner coatings, one to each of the discharging rods. Their outer coatings are either both connected to the patient, or one to the patient and the other to earth. The jars need not be of the same size, and by varying their capacity the strength of the patient's

current may be regulated. The discharging balls are placed together at the commencement of the treatment, and are then separated sufficiently to obtain the required strength of current. Any of the forms of electrodes or pads used in galvanism or faradism may be utilized for this treatment.

As is stated above, this method is generally regarded as a form of high-frequency current, and in accordance with this view is termed by the French writers ' Franklinisation Hertzienne '. When a condenser discharges through a low resistance, the discharge is an oscillating one, but with a high resistance the discharge is unidirectional. In fact, if R be the resistance in the circuit, L the coefficient of the self-induction, and C the capacity of the condensers, and if further

$$R^2 < \frac{4L}{C},$$ the discharge is an oscillating one.

But if

$$R^2 > \frac{4L}{C},$$ the discharge is unidirectional.

Whether a high-frequency current is developed or not in the present case would depend on the resistance in the circuit. The electrical resistance of the patient is very high; the discharge is consequently unidirectional and not an oscillating one.

The treatment is merely effected by the discharge of condensers charged at a very high voltage. Before the spark passes across the gap a charge develops on the outer coatings of each jar; the polarity of this charge is of the opposite kind to that of the discharging rod to which the jars are attached. This charge on the outer coatings of the jars is not free to discharge through the patient until the inductive attraction of the opposite charge on the inner coatings is released by the discharge across the gap; but immediately a spark passes, then the charge on the

outer coating is released and discharges through the patient. This method then amounts to a treatment by unidirectional condenser discharges, for the resistance of the body is too high to permit of any oscillations.

This view of the nature of the action of the static induced current is borne out physiologically and clinically by the definite contractions which are excited synchronously with the passage of each spark. Moreover, Bordier has pointed out that the discharges have a distinct and definite polarity, the excitations from the negative outer coatings being far more powerful than those from the positive. This definite difference in the polar action is conclusive proof that the action of the static induced current is not of a high-frequency character.

The Method of Administration of the Static Induced Current

The patient need not be insulated; the usual rheophores, electrodes, and pads may be utilized. For the treatment of superficial areas and for the treatment of the rectum or vagina, vacuum glass electrodes, such as are used in high-frequency therapy, are very suitable. When using vacuum electrodes it should be remembered that the polarity of the current administered to the patient is the opposite of the charge on the external coating of the jar to which the electrode is attached. That is to say, that if the current conveyed to the inner coating of the jar from the discharging rod is negative, a positive charge is induced on the outer coating, and this positive charge is conveyed to the inner surface of the glass of the electrode, and induces a negative charge on the outer surface of the glass in contact with the patient.

The strength of the current may be adjusted in two ways: (1) by increasing or decreasing the size of the jars, and thus increasing or decreasing the strength of the current.

The French use a form of adjustable condenser, and these seem to possess definite advantages over the fixed sizes used in this country.

(2) The strength of the application may be adjusted by the regulation of the width of the spark gap. The wider this gap, the higher the potential at which the jars are charged, and hence the more powerful their charge.

The Therapeutical Effects of the Static Induced Current

The therapeutic effect of this method is due to its power of exciting contraction in striped and unstriped muscular fibres. In consequence of its very high potential it is very penetrating in its action, and is therefore a suitable means of exciting contraction in deep-seated organs. Bordier (1) has shown, by placing an inflated bladder inside a dog's stomach, connected by a tube with a recording tambour, that the dog's stomach can be made to contract by applying the static induced current to the dog's epigastrium. (This is not a very convincing experiment, as it is not explained by what means contractions of the abdominal walls were prevented from affecting the intra-abdominal pressure during the experiment.) In this way he found that the contraction resulting from an active negative electrode was considerably greater than from a positive one.

The static induced current is chiefly of use in the treatment of chronic constipation, and in conditions where it is desired to excite contraction in deeply placed involuntary muscles. In actual clinical practice the difference of the polarity of the outer coatings of the two jars is clearly seen, and hence, the current being one of make, the active electrode should be connected with the jar of which the outer coating is negatively charged.

High-Frequency Currents from the Static Machine

By connecting the outer coatings of the Leyden jars with a suitable solenoid, a circuit of low resistance and a self-inductance are obtained, resulting in a true high-frequency current. The amperage obtained in this way is very small, and the high-frequency currents so obtained cannot be compared with those yielded by the ordinary diathermy or high-frequency apparatus.

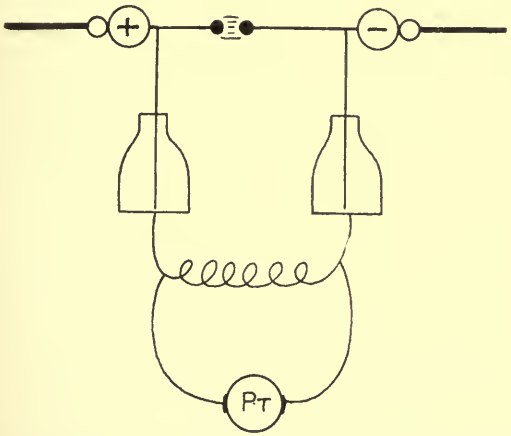

Fig. 17. Diagram showing the method of obtaining H.F. currents from the static machine.

The Nature and Therapeutic Action of the Morton Wave Current

The Morton wave current is by far the most valuable of the currents obtainable from the static machine. It was first described in a paper read by Dr. W. J. Morton, of New York, before the American Electrotherapeutic Association, on September 23rd, 1900.

This current is not of the type that we usually regard as wave currents; on the contrary it is a form of treatment by sudden, and not necessarily rhythmical, or regular discharges.

Mode of Administration. The patient is placed on the insulated platform, the negative side of the machine is grounded, and an electrode, connected by a wire with the positive discharging rod, is applied to the part to be treated.

The discharging balls, in apposition at the commencement of the treatment, are gradually separated to an extent proportionate to the toleration of the patient.

As the balls are separated, sparks pass between them ; in the interval between the sparks, the patient is progressively charged with positive electricity, until the potential

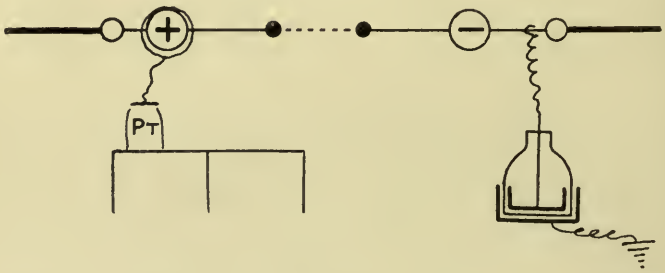

FIG. 18. Diagram of the arrangement of the static machine for the administration of the Morton wave current.

of the static charge of the patient's capacity and on the collecting combs is sufficient to overcome the resistance of the air gap. The patient's capacity then suddenly discharges with the passage of the spark across the gap, and the muscles underlying the pad undergo a sudden and vigorous contraction, the amplitude and vigour of which is directly proportionate to the width of the spark gap and inversely proportionate to the area of the pad employed, or, in other words, is in direct proportion to the density of the discharge.

The contractions excited by the Morton wave current evidently occur at the break of the current, and this is the reason why the positive charge is more efficient in this treatment than the negative charge.

The very low milliamperage utilized to excite a contrac-

tion by the Morton wave current renders this method far less painful than treatment by the galvanic or faradic currents.

As the consequence of the minimum of pain elicited by this method, we are able to employ a voltage so high that the most vigorous contractions involving all the fibres of the muscle are elicited.

Both the amplitude, the frequency, and the type of contraction are under the complete control of the operator. By allowing the sparks to discharge rapidly across the spark gap, the necessary fusion of stimuli may be obtained to excite a very even tetanic contraction, and these series of stimuli may be surged gradually, either by hand or instrumentally. But the real type of the Morton wave current is the slow, steady, heavy, pounding spark eliciting powerful isolated contractions, with a definite pause between each contraction.

The powerful and painless contractions elicited in this manner exercise on the muscles themselves and on the surrounding tissues a kind of 'auto-muscular massage', the effect of which in stimulating tissue drainage and in removing exuded lymph is incomparably greater than in the application of any form of massage applied externally to the surface of the limb.

Where adhesions exist within or in the neighbourhood of the muscles the contractions are necessarily painful at first, but gradually the toleration of a wider spark gap during the treatment indicates the removal of some of the adhesions.

The Morton wave current is extremely useful in the treatment of recent sprains and strains ; the inflammatory exudate, or as John Hunter well termed it 'the coagulable lymph', is readily dispersed, and hence the pain and swelling are quickly relieved, and also the after-stiffness, due to the gluing together of the tissues by the coagulable lymph, is obviated. The efficacy of this treatment is very remarkable, the period of incapacity following a sprain being reduced from one of weeks to one of days. The massage effect of this treatment is well seen in a

recent case of acute synovitis of the knee joint with effusion, the excess of fluid in the joint being frequently dispersed after twenty minutes' treatment.

By employing a suitably shaped electrode, massage of the prostate can be far more efficiently, and with far less discomfort, performed by this method than in any other way. The muscular tissue of the gland itself is in this way excited to contract, and efficient drainage of the gland quickly results.

Mr Frank Kidd (2) states: 'Massage of the prostate in obstinate cases, especially in cases with intense prostatic pain, can be most effectively carried out by using the Morton static wave applied through a rectal electrode, which produces violent but painless contractions of the muscular tissue of the prostate gland.'

Some cases of prostatic hypertrophy yield quickly to the Morton wave current with complete disappearance of the symptoms; but success in these cases naturally depends on the nature of the enlargement. Little hope of improvement can be expected from this treatment in cases of calcareous, malignant, or even fibrous enlargement. The improvement would seem to occur in lax and œdematous conditions of the gland.

One treatment by the Morton wave current often suffices to cure a case of recent lumbago. Supposing this condition to be due to hypertonus of the muscles on the affected side, it would be difficult to conceive a more certain way of overcoming this hypertonus than by the powerful muscular contractions excited by the Morton wave current.

References

1. Bordier, *Précis d'Électrothérapie*, 1902.
2. Kidd, *Common Diseases of the Kidney*.

PART II

THE THERAPEUTIC ACTION OF RADIANT ENERGY

CHAPTER I

THE THERAPEUTIC ACTION OF RADIANT HEAT AND LIGHT

Radiation, or Radiant Energy, is the force transmitted by the ether in the form of waves resulting from the periodic vibration or rotation of electrons.

The Hertzian waves, such as those used in wireless telegraphy, have the longest wave length and the lowest frequency ; they are set in motion by spark discharges from condensers. The next in order of decreasing wave length and increasing frequency are the heat waves. These are set up by the electronic discharges which are excited by the radiation from heated substances. As the waves further decrease in the length, and increase in the frequency of their vibrations, light waves are produced. Light waves extend down through the visible spectrum from the red, orange, yellow, green, blue, indigo, to the violet : beyond which the vibrations become too rapid to stimulate the human retina, and we enter the ultra-violet region of actinic or chemically active rays. Beyond this is the unexplored region, in which the vibrations are too rapid to affect photographic plates or otherwise to reveal their nature and properties by means of any method or appliances at present at our disposal. This region is followed by the region of the Röntgen and the radium rays, in which the intensity of the vibrations set up enables their action to be investigated.

The study of radiant energy is one of the most complex and difficult in the whole range of physical science. So far as therapeutics is concerned, the action of radiant energy may be divided into the action of radiant heat obtained by artificial means; heliotherapy, or the action of heat and light radiation obtained from the sun's rays; the action of ultra-violet radiation; and the action of the radiation from radium and the Röntgen rays.

The Therapeutic Action of Radiant Heat and Light

To a certain limited extent the effects of radiant heat and light vary in accordance with the method adopted for their administration; for, even in the most elementary method, namely, that of heliotherapy, in which the radiant heat and light energy are obtained from the sun's rays, free from the interposition of any filter or absorbing medium other than that of the atmosphere, the effects vary as the treatment is administered at the sea-level or at the high altitude of the Alps.

In the cold sun bath, as administered in the Alps, the snow absorbs some of the heat rays and reflects the light rays; the rarefied atmosphere also filters off less of the ultra-violet rays than the denser atmosphere at lower altitudes.

In the sun bath administered at high altitudes there is thus a maximum of light rays, an increased ultra-violet radiation, and a diminution of the heat rays.

In the warm air of the sun bath of the Mediterranean, though more of the ultra-violet radiation is filtered off, and though there is no snow to reflect the light rays, there is in the hot air little loss of the heat rays from radiation; this, then, is the true sun heat bath, 'loved by swans and lizards, and as a general rule by all living beings' (Laroquette (1)).

Both in the case of the sun bath and in treatment by means of incandescent lamp baths, by far the most powerful action is that of the heat or infra-red region.

Laroquette (2) states that in the solar spectrum there are about six octaves of infra-red rays, about one octave of luminous rays, and nearly half an octave of ultra-violet rays of from 0·4 to 0·3.

The percentage in the spectrum of the incandescent lamps he gives as follows :

	Infra-red Rays.	*Luminous.*	*Ultra-violet.*
Incandescent carbon lamp	93%	6%	1%

The very small amount of ultra-violet rays shows what a very small part this form of radiation plays in the therapy of the light bath. Even in plant life the ultra-violet radiation from the solar spectrum plays little or no part, since the interposition of glass, which cuts off all the shorter radiation, has little or no effect on plant growth.

The very large proportion of heat or infra-red rays in the above table explains why in ordinary clinical practice we detect little or no difference between the effects of radiant heat administered by light baths and the convective heat of hot air baths, or the conductive heat of electrically heated wire resistances, such as the Grevillite appliances, or by the use of hot sand, etc. The greatest advantage of the incandescent light bath consists in the safety, the convenience, and the ease of its administration. In such cases, from whatever source the heat is derived, it is absorbed as heat and its energy is converted in the tissues into some form of increased cellular activity.

There is no basis for the belief which some enterprising instrument-makers seek to inculcate, with a view to the sale of special apparatus, that the colour of the incandescent lamps in any way affects the efficiency of the treatment.

Moreover, there does not appear to be any reason or physical grounds for expecting any marked difference in action between the radiant energy derived from the rays of the sun and the radiant energy obtained from the

incandescent filaments of electric lamps. The superior constitutional effects which are obtained from heliotherapy are to be explained by the conditions under which the treatment is administered, rather than to any special properties peculiar to it.

Heliotherapy is administered under the best conditions, in the open air, usually at sanatoria, where the patient is at complete rest, free from all the cares and worries of business or household duties, where the diet is carefully prepared and regulated to suit the patient's complaint and condition, and where regulations are enforced in respect to early retirement to bed. The treatment is applied gradually, with a low and easily tolerated intensity, for several hours at a time, thus realizing that very important, though much overlooked, rule of physical therapeutics, that it is far better to apply the treatment at low intensities extended over long periods than to apply it intensively for a short time.

Moreover, in heliotherapy there is the invigorating, but unexplained, physical and moral effect, which is excited by bright sunlight, which so cheers and encourages the patient. Unfortunately these superior concomitant effects of the sun bath are but rarely obtainable in this country, and we have to make the best use we can of artificial light and heat baths.

The shorter rays and the higher frequencies of ultra-violet radiation play a very small part in the treatment by incandescent light baths. The fact that pigmentation follows prolonged exposure to the incandescent lamps, whether of the smaller or the larger type, is not attributable to the action of ultra-violet radiation: in such cases the pigmentation is due to the prolonged but weaker pigmenting action of the blue and violet rays.

The infra-red and the red rays have no pigmenting effect, but they have a more penetrating action, reaching the subcutaneous regions, and dilating the capillaries in those parts. By their prolonged action deeper effects are

consequently obtained, and these are shown by the deeper œdema of the tissues which results from their intensive application.

The effect of the incandescent light baths is to increase the temperature of the skin and subcutaneous tissues and so to increase the cellular activity of these regions: this is shown by the increased sweating which follows their application.

In fact, the sweating which follows the application of the enclosed light baths is apparently far greater than that which follows the treatment by the sun bath, where the part under treatment or the whole body is exposed to the free circulation of the air, and consequently the moisture of the skin rapidly evaporates.

The bactericidal action of these baths may be disregarded; only the least resisting of bacteria are destroyed even by sunlight, and their destruction is due more to desiccation than to any direct action of the radiation.

There is one very interesting point which has been raised abroad, and also in those sanatoria in this country where the sun bath has been employed for the treatment of tuberculous glands, bones, or joints.

It has almost invariably been noticed that no improvement has resulted from the sun bath unless pigmentation has occurred. And this has been found to be so universally the case that the relationship has been regarded as one of cause and effect. Laroquette (3) points out that this inference is an incorrect one, and that the relationship is explained by the fact that only those cases are capable of improvement whose cells have sufficient vitality to respond to the stimulus of the radiation. The correlation is not therefore one of cause and effect; but merely shows that the radiation affords a valuable method of prognosis, by differentiating, by means of the occurrence or absence of pigmentation, between those cells which have sufficient vitality to respond to the radiation and consequently possess the power of recovery, and those cells whose

vitality is too far lowered to admit of any response to the radiation and consequently have not the power of recovery or improvement. This point has further some practical importance, for it has been wrongly urged, by those who maintain a cause and effect relationship, that no form of treatment, such as ultra-violet radiation, should be adopted, which would tend to prevent subsequent pigmentation on exposure to sunlight.

To sum up the effects of heat and light radiation, we find that these forms of radiant energy are conveyed to, and are transformed into heat in, the skin and subcutaneous tissues. And we find that, clinically, little, if any, difference occurs in the therapeutic action, whether this heat is conveyed to the tissues by the conductive heat of paraffin wax baths, hot sand, or the electrically heated wire resistances of the Grevillite apparatus, or whether it is conveyed by convective heat as by hot air, or applied as radiant heat by means of incandescent lamps. The choice of method should be decided upon grounds of convenience, safety, and efficiency. Acting on this principle, the incandescent lamps, either in the form of a battery of 16 c.p. or 32 c.p. carbon lamps, or one large 500 c.p. carbon filament leucodescent lamp, or the heliodescent lamp of 2,000 c.p. with metal filament, will be selected. The enclosed battery of small lamps should be selected where it is desired to excite profuse perspiration, and either the leucodescent or the heliodescent lamp will be found useful where it is desired to observe the degree of heating during the treatment, or to treat certain irregular surfaces to which the collection of smaller lamps cannot conveniently be applied. Nephritis may be treated, with a view to promoting profuse perspiration and consequent relief of the kidneys, by a trunk bath containing about sixteen incandescent lamps of 16 or 32 c.p.

Light baths surrounding the whole body, with the exception of the head and face, may be utilized ; and to

some of the baths three arc lamps are added, but the benefits derived from their use do not compensate for the additional expense and complication that they entail. The trunk bath, or two trunk baths, the one covering the trunk and the other the legs of the patient, are equally efficient as the full body bath, and are far less expensive and cumbersome. Such a combination of baths is useful for the treatment of neuritis or rheumatism, when it is distributed over the whole or greater part of the body. The smaller baths are usually employed for the treatment of rheumatism or neuritis of the joints or limbs, or as a preliminary to massage.

With more or less regular periodicity some new method for the administration of heat is introduced, and enjoys an ephemeral vogue, raising the hopes of credulous patients, enriching the instrument-makers, affording material for discussion at scientific societies, but ultimately failing to advance in the slightest degree either the science or practice of heat therapy. The latest introduction of this kind is the paraffin wax bath. Paraffin wax, with a melting-point slightly above the fever temperature of the body, is heated by a complicated and expensive electrical apparatus to a temperature of 150° F. or more, and the hand or part to be treated is plunged into the wax at this high temperature. All such minor considerations as the coagulating temperature of albumen are overlooked, and it is held that by the use of this paraffin wax bath we are able to make use of this enormous heat for the treatment of chilblains, neuritis, and a heap of other conditions.

Fortunately, this method does not abrogate entirely the laws of physics, and when the hand or other part is plunged into the bath, a layer of consolidated paraffin wax immediately forms upon it, and, this layer of consolidated wax being an efficient non-conductor of heat, no ill effects ensue from an undue temperature.

The lower the temperature of the wax, the thicker is the

coating which is deposited on the hand. This film prevents any heat radiating from the hand, and also prevents any excess of heat being conveyed to it. It also blocks all escape of perspiration from the treated part, until the covering is removed, when the previously restrained sweat pours forth freely. The treatment is said to leave the part to which it is applied in a favourable condition for massage, manipulations, and movements, though many masseuses prefer the older, but less greasy and messy, method of soaking in hot water. Apart from its complication and cost, this method would appear to possess little disadvantage beyond a liability to produce eczema, possibly due to the obstruction of the sweat glands which the treatment causes, but some electro-therapists claim for it an unexplained therapeutic action unobtainable by other means.

References

1, 2, and 3. De Laroquette, 'Actions des Bains de Lumière naturelle et artificielle', *Archives d'Électricité Médicale*, July 25, 1912.

CHAPTER II

ULTRA-VIOLET RADIATION

THE wave length (symbolized by the Greek letter lambda, λ) of light is usually stated in Ångström Units. An Ångström unit is the wave length of soft X-rays, i.e. $1/10^{-10}$ (1/10,000,000,000) of a metre.

The wave length of the visible spectrum commences at the beginning of the red end of the spectrum, λ 7,500 A.U., and extends to λ 3,900 A.U. at the end of the violet. At this wave length the ultra-violet spectrum commences and extends for therapeutic purposes to λ 1,850, where the atmosphere absorbs all the shorter radiations, and they consequently cannot be utilized for treatment purposes. Schuman and Lyman have extended the ultra-violet spectrum, by the use of special methods, up to λ 600, and more recently Millikan has added a further extension to λ 360, beyond which is an unexplored region until the special properties of X-rays enable the radiation of soft X-rays to be investigated. The value of the soft X-rays, as previously stated, is that of one Ångström unit. Hard X-rays from a gas tube are equal to about 0·25 A.U. The hardest X-rays obtainable from a Coolidge tube are about 0·14 A.U., and the very penetrating gamma rays from radium have a wave length of about 0·07 A.U.

The Action of Ultra-violet Radiation

The earliest paper with which I am acquainted to allude to the lethal action of the actinic or chemical rays (i.e. the ultra-violet rays) on bacteria, appeared in *The Proceedings of the Royal Society* of December 26, 1877. This was a paper entitled ' Remarks on the Effect of Light on Bacteria and other Organisms ', by A. Downes and

T. P. Blunt. The experiments therein described were performed chiefly to show the retarding effect of sunlight on the development of hay bacilli placed in thin glass test-tubes. The authors made the significant observation: 'We have invariably found it a difficult matter to sterilize an ordinary cultivation liquid, when a second screen of glass was placed between it and the light.'

This passage clearly shows that the retarding effect on putrefaction was due to the higher frequencies of the radiation, which were cut off by the interposition of the glass screen, and the authors concluded, as the result of their experiments, that 'the preservative quality of light would appear to be chiefly, but perhaps not entirely, associated with the actinic rays of the spectrum'.

In 1887 Hertz pointed out that the discharge across a spark gap took place more readily when ultra-violet light fell upon it. Ebert then showed that this action occurred at the negative pole, and it was subsequently shown to be due to the fact that a negatively charged body readily loses its electrical charge when ultra-violet light falls upon it. Thus it was established that the photo-electric action of ultra-violet light consists in the discharge of electrons from a negatively charged body 'or the acquisition of a positive charge under the action of light. This is traced to the emission of electrons from the illuminated surface' (Allen).

Hertel, as the result of his investigation into the lethal action of ultra-violet radiation on bacteria, concluded that the action was due to reduction, because he found that, probably owing to the protection obtained from the oxygen supplied by the chlorophyll, green hydræ were less affected by ultra-violet light than the colourless ones. He also found that oxyhæmoglobin was reduced, and that, when the brain of a rabbit, coloured blue by the action of alizarin blue injected into the veins of the animal, was acted upon by ultra-violet light, the blue colour disappeared as the result of the action of the light.

It was found during the war that the cotton wings of the aeroplanes quickly perished under exposure to sunlight at the higher altitudes, and ' dope ' was consequently applied to protect them from the shorter wave lengths of the ultra-violet region. Some interesting experiments were performed in the investigation of the cause of this deterioration. Strands of cotton were exposed to different parts of the spectrum, and by delicate apparatus their breaking strain was subsequently tested. The tabulated breaking strains thus recorded gave a numerical representation of the spectrum, the least breaking strain being recorded for those strands which had been exposed to the shorter rays of the ultra-violet region.

There appears, then, to exist an accumulation of evidence, derived from different sources and from various observers, that the action of U.V.R. on the tissues is one of oxidation or reduction. But in what way is this action produced ? By what means does it exercise its therapeutic effect on the tissues ?

It is impossible to appreciate an answer to the first question unless we possess some conception of the structure of the atom.

Until the discovery of X-rays by Röntgen, the atomic theory, foreshadowed by the Greek philosophers, formed the fundamental basis upon which the science of chemistry was erected. Among the many wide-reaching results that have followed Röntgen's discovery, none has had a more important or revolutionary effect than the knowledge which has been obtained by its means of the structure of the atom.

It is now held that the atom is made up of a number of electrons (particles of negative electricity) held together by the electrostatic attraction of a central complex nucleus with an aggregate positive charge equal to the number of outside electrons. The chemical properties and the characteristics of the different atoms depend upon the number and grouping of these electrons. The

simplest form of atom is that of hydrogen, which has only one electron ; the next in order of simplicity of structure is the helium atom, with two electrons. The atoms of the various elements possess an increasing number of electrons, until we arrive at lead with 82 and radium with 84 electrons. The arrangement of the electron in relation to the central nucleus is of importance from the point of view of atomic and molecular stability. Langmuir suggests that the electrons are arranged concentrically round the central nucleus of positive electricity ; if there are not more than two electrons, they are arranged in one concentric ring ; if more than two electrons, the next eight are arranged in a second concentric ring, further removed from the electrostatic attraction of the central nucleus of positive charge. As the number of electrons, comprising the atom, increases in number, there is another layer of eight ; then one or two layers of eighteen, and if there are still more electrons, there may be an outer layer of thirty-two electrons. The arrangement of the electrons in the second and third layers is a symmetrical one, the electrons taking up a position as at the eight corners of a cube (Langmuir) —an arrangement termed octets, presumably due to the mutual repulsion of the electrons bearing a similar charge. The chemical activity of the atoms depends on the readiness with which they take up or part with electrons. These electrons are grouped in this form in a very open network. Langmuir has given an ingenious simile which enables us to visualize the relative minuteness of the particles which we are considering. He states that if a lump of matter, the size of a base-ball, were magnified to the size of the earth, the atoms of which the lump of matter was composed would then have become the size of the base-ball. Or, in other words, the relative size of the atom to the base-ball is that of the base-ball to the earth. He further illustrates the open network in which the electrons are arranged, by supposing that if the diameter of the atom is one mile, the nucleus would then

be the size of a walnut, and the electrons would be about 5 feet in diameter. This method of realizing the minuteness of the particles may be completed by recalling the simile of another writer, that if we imagine an ordinary buck shot covered with electrons, then increase the size of the electrons until they are of the size of the buck shot, and next increase the size of the buck shot in a similar ratio, the buck shot will become 48,000 times the size of the earth.

The electrons within this loose network of the atom rotate in an electrical field exercised by the positive charge of the central nucleus. The stronger the electrical field the firmer is the combination of the molecules composed of these atoms, and to a corresponding extent the chemical activity of these molecules is reduced. Now light, in accordance with the Law of Grotthuss, is only active when it is absorbed, and is only absorbed, when its wave length is in resonance with, that is to say, when its vibrations correspond with, those of the atoms upon which it falls. It consequently follows that the molecules composed of the atoms with higher natural frequencies will be acted on by the shorter wave lengths of the ultra-violet end of the spectrum; these are generally more stabile and less chemically active than those molecules whose vibrations correspond with the longer wave lengths of the red end of the spectrum. The effect of this absorption of waves of similar length is an activation of the absorbing molecules acted upon, usually resulting in oxidation or reduction.

We thus conclude that the effect of U.V.R. is to produce an oxidation or a reduction of those molecules whose vibrations have the same frequency as the radiation which falls upon it; and that this oxidation or reduction is the result of the resonant agitation excited in the atoms.

How does Ultra-violet Radiation exercise its therapeutic effect on the tissues?

First of all, we must consider what the therapeutic effects of ultra-violet radiation are. Ultra-violet radiation has undoubtedly a very destructive action on bacteria, but this property has but little application clinically, owing to the fact that the shorter and more lethal rays cannot penetrate to a sufficient depth to reach the bacteria. By far the most valuable result obtained in clinical practice from the application of ultra-violet radiation is the lasting hyperæmia which its efficient application induces. A superficial erythema, lasting for a week or ten days, is readily produced by this means, so that an increased blood supply, and consequently increased nutrition, may be superficially maintained by the repetition of the application twice a week. Further proof of this is found in the fact that the therapeutic application of ultra-violet radiation is especially indicated, and that it proves most beneficial in those cases where the blood supply and nutrition of superficial areas are impaired: as, for instance, in alopecia areata, chronic eczema, indolent wounds, etc.

After the application of ultra-violet radiation a latent period of about five or six hours, varying with the intensity and wave length of the radiation, elapses before the characteristic erythema appears. During this latent period nothing is noticed, and it is, indeed, comparable, except for its shorter duration, with the latent period following a full skin dose of X-rays. Any satisfactory explanation of the therapeutic action of ultra-violet radiation should also explain this latent period. It is not sufficient to state that ultra-violet radiation produces an oxidation of the molecules of which the tissues are built up, for such a statement in no way explains the occurrence of this latent period.

It has been suggested that the oxidizing action of the

ultra-violet radiation may result in the production of ozone within the tissues, and that the erythema is the result of the irritation excited by that product. The erythema from such a cause would probably be more immediate and less lasting in its action.

A very suggestive fact, both in this connexion and in connexion with the action of X-rays, between which and the action of ultra-violet radiation the difference is one of degree rather than of character, is the possibility of obtaining a photograph of the nucleus of a cell by means of ultra-violet radiation.

Köhler has obtained, by means of ultra-violet radiation at λ 2,800 A.U., photographs of the dividing nuclei of the cells in the gill plates of Salamander larvæ, in which the chromatic substance was so opaque as to appear as if stained (Bayliss).

According to modern views, the so-called selective action of X-rays is upon the chromatin of the dividing nuclei. The dense opacity of the chromatin, when photographed by ultra-violet radiation, shows the completeness with which this substance absorbs the shorter wave lengths, and forcibly suggests a special or 'selective' action upon it by ultra-violet radiation.

The suggestion consequently arises that the hyperæmia excited by ultra-violet radiation may be due to some toxin[1] derived from the splitting up of the chromatin, by means of which an increased blood supply is stimulated. The same theory would apply, though in a more pronounced degree, to the action of X-rays, and would serve to explain the latent period following the two forms of radiation.

Upon the extent to which the chromatin was split up would depend the intensity of the effects, a stimulating reaction resulting from the milder action of the ultra-violet radiation and a weak application of X-rays, whilst

[1] That the production of such a toxin results from exposure to X-rays is shown by the experiments of Curshmann and Gaupp. See page 239.

a destruction of the cells affected would result from an intensive X-ray treatment.

The general absorption of such a toxin would also serve to explain the severe constitutional effects which sometimes follow upon the intensive application of X-rays at several points of entry, as in the Freiberg method of intensive radiation of fibroid tumours of the uterus.

Upon such a hypothesis the answer to the question propounded above would be that ultra-violet radiation exercises a special action upon the chromatin of the nuclei of the superficial cells of the body leading to the formation during a latent period of a toxin, which exercises a stimulating effect upon the local arterioles.

From the foregoing theories and hypotheses, the following practical conclusions may be deduced : that, since it is impossible, in the present state of our knowledge, to predicate which particular wave length will most efficiently produce the desired result in any individual case, and since no ill effect has ever been recorded as resulting, either from too intensive an application of ultra-violet radiation in clinical practice, or from too long an exposure to such radiation in those industrial occupations in which it is employed, the radiation utilized should be as intensive, and its wave length should be as continuous, as possible throughout the whole of the ultra-violet spectrum which is available for treatment.

The number of electrons emitted by the action of ultra-violet radiation is directly proportional to the intensity of the radiation. And, hence, in accordance with the law of Bunsen and Roscoe, the time required to produce a given reaction is directly proportional to the intensity of the radiation. The intensity of the radiation will vary with the amperage employed. With the higher amperage more energy is brought to play, and thus the efficiency of the method is much increased. The electrodes should be of as large a diameter as can be conveniently used, in order that they may not be consumed too quickly with

the high amperage employed, and should be of such a nature as to yield as complete and as intense a spectrum in the ultra-violet region as possible.

Ultra-violet radiation may be generated either by a spark or by the arc discharge; but as the spark discharge does not yield a sufficient volume of light for therapeutic purposes, the latter method is the one usually chosen. When a substance is heated to incandescence, as in the case of the filaments of incandescent lamps, a continuous spectrum is obtained common to all metals in a state of incandescence, and the composition of the filament in no way affects the character of the radiation. The spectrum of incandescence stops abruptly at about λ 3,700 A.U., and is consequently of no practical value for ultra-violet treatment. When metal rods are employed as electrodes in the electric arc, they become heated to volatilization, and yield a type of spectrum that is specific to the metal employed.

The carbon arc, the mercury vapour arc, the iron arc and spark, the Simpson (wolfram) arc, and the tungsten arc are the sources most commonly employed for therapeutic purposes. The carbon arc has the distinction of having been the one selected by Finsen, who did the pioneer work on this subject, and whose investigations have been of the greatest value. The carbon arc is not, however, a rich one in the shorter wave lengths of the ultra-violet region, and the Finsen lamp necessitates an exposure of about seventy minutes, a current consumption of about 80 amperes, and an area of only about an inch in diameter is treated at a single treatment. The iron arc is very rich in ultra-violet radiation, containing some very intense lines, but it only extends to wave length 2,250, and its spectrum is not so continuous as that of the tungsten arc.

The mercury vapour lamp, the best-known type of which is the Krohmeyer lamp, does not yield by any means a continuous spectrum, but exhibits isolated lines

of very short wave length in the neighbourhood of the region of atmospheric absorption. Before the war I used the Krohmeyer lamp in hospital practice, but without obtaining any very satisfactory results. Dr. Jansen, of Copenhagen, tells me that he has investigated the comparative results obtained in the treatment of lupus by the Finsen lamp and by the mercury vapour arc, and that he found the latter by no means as efficacious as the former. He attributes the superior action of the carbon arc in the treatment of lupus to its richer yield of radiation in the longer and more penetrating wave lengths of the violet end of the ultra-violet spectrum.

Schunck, in a paper entitled 'A Spectroscopic Investigation of some sources of Ultra-violet Radiation in relation to treatment by Ultra-violet Rays', reported that the spectrum of the tungsten arc, and also the arc of wulfram (Simpson electrodes), 'consists of many lines of nearly equal intensity throughout the ultra-violet region, so close together as to form an almost continuous spectrum, extending with but slight loss of intensity to λ 2,140 (the limit of the instrument employed)'. Schunck also remarked that the tungsten spectrum, and that from the Simpson electrodes, extended farther with the same amperage and exposure than that of any of the other sources that he examined; and among other sources he tested the following: molybdenum, iron, carbon, carbon rods impregnated by boiling in solutions of sodium tungstate, uranium nitrate, ammonium molybdate, and titanous chloride, and half-inch cored carbons filled with U_3O_8, Fe_2O_3, and wulfram and tungsten powder.

Now, since the main therapeutic effect of ultra-violet radiation is the result of the hyperæmia induced by exposure to the radiation, it follows that the intensity of the erythema and the readiness with which it is produced may be taken as a measure of the efficiency of the different sources of radiation.

Experiments conducted by Schunck on this basis, by

exposing the flexor surface of his forearm to radiations derived from different sources, clearly showed that an erythema was far more readily and intensively induced by the tungsten and wulframite electrodes than by any other source of ultra-violet radiation.

The credit of the discovery of wulfram (the ore of tungsten) as a source of ultra-violet radiation belongs to an electrical engineer, the late Mr. Simpson, who, it is stated, in the course of his investigations into the nature of the rarer ores, found that the hands of his workmen, suffering from eczema, became cured when exposed to the radiation of what were termed ' Simpson electrodes '. The composition of these electrodes was zealously guarded: the discovery, as is usual when therapeutic measures are introduced by those ignorant of the nature of diseases, was loudly boomed in the daily and the illustrated weekly press as a new form of X-ray, and extravagant claims were made for its curative properties in all kinds of diseases. Fortunately, instead of, as is far too commonly done by the medical profession, ignoring these claims and pronouncing them, untried, as quack discoveries, the properties of the Simpson electrodes were spectroscopically investigated by Professor Sidney Russ, and clinically by Dr. Sequeira: with the result that the identity of the electrodes with wulfram was spectroscopically proved, and their therapeutic properties were shown to be those of ultra-violet radiation.

These Simpson or wulfram electrodes burnt so unevenly in the electric arc and with so much spluttering and interruption that I obtained from the Thomson, Houston Co., of Rugby, some ' swaged ' or highly compressed rods of pure tungsten, 0·25 inch square, which burn so evenly and satisfactorily that I still continue to use them in both my private and hospital practice. These rods are very highly compressed by a special process to enable them to be drawn out without fracture in the manufacture of the fine tungsten filaments for incandes-

cent lamps. The high compression of the rods obtained in this way enables a current of 15 amperes to be passed through them without any spluttering taking place.

The ingenuity of some instrument-makers has been much exercised in designing complicated and expensive arc lamps for the administration of ultra-violet radiation, but a simple arc lamp, such as is used for small cinema lamps, capable of carrying a current of 20 amperes, costing from £3 to £6, is preferable to the lamps of the instrument-makers costing from £30 to £40, many of the additions to which merely serve to cut off some of the radiation.

The other fittings needed are a nickel-plated concave reflector, to be held in the hand of the operator, by means of which he can at the same time protect his own face and adjust the focus of the radiation to the movements of the patient. A quartz lens, of about 4-inch focus, is also needed ; it should be mounted in a circular shield of light material to protect the untreated parts from the radiation. (It should be remembered in administering the treatment that the focus of ultra-violet radiation is slightly shorter than that of visible light.) Hooded glasses, of Crooks No. 4 glass, should be provided for the protection of the eyes of the patient, operator, and assistants.

A continuous current supply of at least 100 volts is needed to yield the required current of 15 amperes. The energy obtained from a current of 15 amperes enables far better results to be obtained than when employing lower current strengths.

Since one-tenth of a millimetre thickness of skin cuts off the ultra-violet spectrum approximately at λ 3,000 (Russ), there is no advantage to be gained by the use of quartz compression when employing the shorter radiations of ultra-violet radiation ; slightly deeper penetration of the blue, violet, and the longer wave lengths of the ultra-violet radiation may, however, be obtained by the compression of the part treated.

CHAPTER III

THE THERAPEUTIC ACTION OF X-RAYS

RADIOTHERAPY, or the treatment of disease by X-rays, forms an integral part of the province of the electrotherapist ; and its development in the past has been considerably hindered by its too exclusive association with the work of the radiographer. During the late war the resources of radiotherapy were not utilized to anything like their full extent, owing to an idea, prevalent with the authorities, that its administration should rest solely in the hands of the radiographic expert. Apart from the fundamental identity of the instruments employed, there is little in common between the sciences of radiography and radiotherapy ; the type of instruments suitable for the former becomes more and more unsuitable for the latter, and vice versa, as the two sciences mutually develop.

Moreover, as the result of the urgent and immediate nature of the demand for radiography during the war, the radiographers had no time at their disposal for radiotherapy, which consequently remained in almost complete abeyance, and nearly all our knowledge of its action in the resolution of scar-tissue, in the treatment of nerve injuries, etc., is derived from the investigations of French workers.

On the other hand, treatment by X-rays is so intimately associated with other forms of electrical treatment that no electrotherapist can afford to overlook, or remain ignorant of, the science and practice of radiotherapy. Just as there is no sharp line of demarcation between the regions of the shorter wave lengths of ultra-violet radiation and soft X-rays, so many of the diseases amenable to X-rays and other forms of electrical treatment exhibit symptoms which at one time will call for the one form of treatment and at another time will be best met with the

other. The electrotherapist, who is acquainted with and experienced in both methods, will alone be able to predict which of the two, under certain circumstances, will be the more likely to ameliorate the symptoms, or effect a cure. The truth of this is seen in the treatment of such divergent conditions as acne and sciatica.

The Action of X-Rays

At the present time the Coolidge tube so far exceeds in therapeutic efficiency any other tube in general use in this country that its action will be chiefly considered.

When the tungsten filament attached to the kathode of the Coolidge tube is electrically heated by the heating circuit, electrons are thrown out from it in proportion to the degree of heating. The exhaustion of this tube is, in its manufacture, carried to such a high degree that, until such electrons are emitted from the kathode, there are no ions or electrons to carry the current from the kathode to the antikathode.

The number of electrons emitted from the antikathode will depend upon the degree to which it is heated, and the amount of current carried across the tube with a given voltage will vary proportionately ; conversely, the lower the heating current, the higher will be the voltage required to force a current through the tube. That is to say, as the heating current is decreased, the potential from the source of supply, induction coil, static machine, or transformer, or whatever source is employed, must be increased ; consequently the energy of the electrons, or the force with which they are hurtled against the antikathode, is correspondingly increased. Upon the energy with which the electrons impinge upon the antikathode, the frequency of the resulting X-rays will depend. The greater this energy, the higher will be the frequency of the radiation which the electrons emitted from the antikathode will give rise to, namely, the harder and the more penetrating will this radiation become.

We are thus able, when employing the Coolidge tube, by increasing the subsidiary heating current, the potential of the main source of supply remaining the same, to increase the milliamperage passing through the tube, at the same time producing softer and less penetrating radiation. Or by increasing the potential of the main supply, the heating current remaining the same, the current passing through the tube is lessened; but the hardness or penetration of the resulting radiation is increased.

The antikathode of the X-ray tube may be regarded as a transformer which converts the energy of the electron hurled against it from the kathode into X-rays, and the greater the potential of the source of supply, the greater will be the energy or hardness of the resulting radiation. But, though all the electrons from the kathode may strike the antikathode with equal energy, the resulting radiation will not be homogeneous (namely, all the rays will not have a similar degree of frequency). For those electrons which are shot off from the surface of the antikathode will have lost none of their energy, and will excite a radiation of the maximum frequency and hardness: whilst the electrons emerging from a short distance below the surface of the antikathode will have lost some of their energy in forcing their way to the surface, and will consequently give rise to a radiation of longer wave length, of lower frequency, and of less hardness. Consequently the emanation of radiation from the antikathode, resulting from the energy of the electrons striking it, whatever their energy may be, will be heterogeneous. That is to say, the radiation will consist of a widely varying range of frequency or hardness, the upper limit of such radiation being dependent upon the energy imparted to the electrons shot off from the kathode by the potential of the source of supply.

The X-rays, excited by the discharge of electrons from the antikathode of the X-ray tube, reproduce the mechanism

of their own production upon the material or substance upon which they fall, discharging electrons or soft β-rays from them by the resonant agitation which they set up. If the material upon which the X-rays fall contains no element with an atomic weight greater than 40, what have been termed ' scattered rays ' are produced : but if the X-rays fall upon an element with an atomic weight greater than 40, ' secondary radiation ' is excited. In this latter case the X-rays falling upon a substance with the higher atomic weight discharge electrons from it with such energy that they in turn excite secondary radiation, the type of which varies with the nature of the material upon which the X-rays fall, the type of secondary radiation emanating from silver differing widely from that derived from aluminium, and so on.

As light has no action upon any body upon which it falls, unless some absorption takes place, so X-rays are said to have no action upon any substance unless the rays are absorbed, scattered, or transformed. This practically amounts to the same thing, for in all these processes there must be some absorption of energy.

The Therapeutic Action of X-Rays

From the foregoing brief *résumé*, adapted from the writings of the leading authorities, of the physical nature and action of X-rays, it will be seen that their fundamental action is the discharge of electrons from the bodies upon which they fall. Such an action we have already seen to be the characteristic of ultra-violet radiation ; but, in the case of X-rays, the energy is so much greater that the electrons are emitted with such force that they themselves are capable of exciting radiations, the nature of which depends upon the nature of the substance upon which the X-rays fall.

The effect of secondary radiation is well shown by the so-called ' X-ray burns ' of the skin, which have occurred when a metal filter has been applied, during the adminis-

tration of X-rays, direct to the skin of a patient without the interposition of any absorbing medium, such as chamois leather; the soft and readily absorbed secondary radiations, in such cases, cause a 'burn' of the skin. An instance of such an X-ray burn from secondary radiation has recently been recorded by a radiologist, who himself received such an X-ray burn from the secondary radiations excited by the metal of a wrist watch during the course of X-ray administration.

An attempt has been made to explain the therapeutic action of X-rays by the action of these secondary radiations on the iron in the hæmoglobin of the blood and on the salts in the tissues.[1] If such were the case, the danger from the secondary radiation in the use of barium and bismuth meals would be a very real one, the secondary radiation from barium and bismuth, with atomic weights respectively of 137 and 208, being very considerably greater than that from iron with an atomic weight of 56. Probably the influence of secondary radiation and scattered rays within the tissues would be merely a slight intensifying one, analogous to but less than that of the intensifying screen sometimes employed in radiography. The more rational view to take of the therapeutic action of X-rays is to regard them as an intensified form of the action of ultra-violet radiation. Such a view is in accordance with the now accepted fact that the ionization produced by X-rays is due entirely to the electronic discharge or β radiation, and not in any way due to the action of scattered or secondary radiation.

We have regarded the action of ultra-violet radiation as due to the oxidation or reduction in the tissues resulting from the changes in valency produced by the

[1] The irradiation of the blood tends to show that the effects are not the result of secondary radiation, for the red blood corpuscles with their iron-containing hæmoglobin are scarcely affected by a radiation of moderate intensity; whilst the nucleated white corpuscles are much reduced in number.

electronic discharge caused by the resonant agitation excited in the cells by the radiation. And we have attempted to show that ultra-violet radiation has a selective action on the chromatin of the nucleus of the cells, when the metabolic activity of the cell is at its maximum at the time of division, splitting it up and thereby possibly setting free a toxin, which, varying with the intensity of the radiation, may have a stimulating or a destructive effect on the tissue cells. Such a hypothesis as this is in full accord with the views propounded in a very valuable and suggestive paper, entitled 'Fondements rationnels, Indications techniques et Résultats généraux de la Radiothérapie des Cancers', by Dr. Claude Regaud (1), Director of the Biological Laboratory of the Paris Radium Institute.

In this paper Dr. Regaud discusses the subject from the point of view of the surgeon, and commences by pointing out that the view generally held by surgeons that X-rays act, and should act, on cancerous growths in the manner of a caustic is a wrong one. The error doubtless originated in the first place, and in the past was justified, when unfiltered—that is, too soft—X-rays, of little penetrating power and easily absorbable radiations, were employed. The main object of the paper is to urge the employment of the selective cytocaustic ('élective cytocaustique') action of very hard X-rays and the very penetrating gamma rays of radium. He states that certain cells are peculiarly radio-sensitive to hard X-rays administered in a suitable dosage. 'For example, it is possible to cause the disappearance, completely and definitely, of a subcutaneous tumour, such as a globo- or lympho-sarcoma, by radiation filtered through 7 to 8 mm. of aluminium, without the skin presenting any other change, beyond, perhaps, sometimes the falling out of the hair or beard. This cytocaustic action clearly shows the selective action of the rays on two types of cells, i.e. the cells peculiar to the sarcoma, and the generating cells of the hair follicles.'

Dr. Regaud argues that, from the point of view of their receptivity, there is a very extended range of difference between the more sensitive cells, such as those of the sexual organs and the leucocytic glands, and the far less sensitive cells of structures, such as nerves and muscles. And that this variation in receptivity is to a large extent analogous to the selective action of specific drugs, such as the action of digitalis, curare, or the tetanic toxin on certain cells. This radio-sensibility is not, however, the special property of any type of cell; but is 'inherent to certain states, or physiological moments in the life of the cell. The most important and the best known of which is the state of reproduction.' Cells which are preparing for division, cells undergoing division with short intervals of rest, cells exercising a secretory function, are specially sensitive, the period of greatest radio-sensibility corresponding to the maximum metabolic activity of the nucleus. This period of maximum metabolic activity is a short one, consequently the period of maximum radio-sensibility is also a brief one. The special radio-sensibility of cancer cells is due to their indefinite reproduction.

'Since then hard X-rays and gamma radiations are antagonistic poisons to cellular reproduction, from this very fact they become curative agents of cancer. Experience has actually shown that a malignant tumour, well localized and suitably situated for radiation, can be completely and absolutely dispersed.'

There is a very wide range of radio-sensibility, and though every malignant tumour is more radio-sensitive than the surrounding tissues and the tissues which it penetrates, nevertheless, there is a very wide difference in the radio-sensibility of different neoplasms. The most radio-sensitive of malignant growths are the lympho-sarcomata, and the least sensitive are the epidermal epitheliomata. Between the radio-sensibility of the latter type of malignant growth and that of the normal tissues

the difference is only slight, and consequently the radiotherapy of such growths is not unattended with danger.

Dr. Regaud emphasizes the fact that his remarks only apply when hard X-rays or gamma radiations are employed. 'The action of hard X-rays, or gamma rays thus brings about, more or less rapidly, the death of the cells. A less sensitive cell is chiefly affected in its power of reproduction: this may perhaps be impaired for a time; or, if the cell continues to divide, the descendants are affected by malformation and degeneracy, which brings about their death after some generations.' This result Regaud points out is due to the ascertained fact that hard X-rays and gamma radiations are the selective poisons of the nuclear chromatin, 'which, as every one knows, is the support of heredity. It is this, that the radiations suppress, or suspend in the reproductive cellular tissue.'

Though it has been experimentally shown that very small doses of X-rays exercise a stimulating action on cell growth, the margin between a stimulating and an inhibitory dose is so small and so unknown a quantity that it is safer to achieve a stimulating action by diathermy or other means, and to reserve the use of X-rays for the purpose of restraining the growth of or destroying as far as possible the cancerous cells.

If, as Dr. Regaud points out, the real selective action of hard X-rays and gamma radiation is upon the chromatin of the nuclei of the cells in a state of division, an important line of research is opened up to ascertain by what means the maximum number of cells of the tissues to be destroyed may be brought to the most active state of nuclear division at the time the radiation is applied. In this connexion, some observations, which I first made in 1919, may be of interest. After treating some cases of acne of the face by intensive ultra-violet radiation from the tungsten arc, I found that in some instances the thickened acne nodules had not completely resolved. To effect

their resolution, I applied ½ and ⅖ pastille doses filtered through ½ mm. of aluminium. I was surprised, and at first rather alarmed, to find that I obtained a definite X-ray erythema with even these small doses. I subsequently reported this occurrence to two well-known radiologists: the first was rather an alarmist, and remarked that he did not like these erythemata; he had so often seen telangiectasis follow them after many years. Fortunately the erythema so produced was mild in character, of short duration, and unattended by any untoward symptoms, so my mind was soon at rest. The other radiologist had experienced the same result, and exclaimed enthusiastically, and quite correctly: 'But don't such cases do well?'

The explanation, in accordance with the theory of Dr. Regaud, that naturally suggests itself, is that the superficial cells were in a peculiarly radio-sensitive state, due to the active cell division resulting from the previous erythema, excited by the intensive ultra-violet radiation. If such a conclusion is correct, we have in ultra-violet radiation a ready means for exciting an increased radio-sensibility of the superficial tissues, and the point for inquiry arises: Can we by diathermy, or other means, increase the metabolic activity, and hence the radio-sensibility of cells previous to their undergoing destructive radiation?

As a matter of fact, it has already been stated that the previous application of diathermy has an adjuvant action in deep radiotherapy, and its beneficial action has been attributed to an increase in the secondary radiation from the iron of the hæmoglobin brought about by the increased blood supply. In view of Dr. Regaud's work, the increased cellular activity would appear to be the more rational and probable explanation.

Perhaps the best way to obtain this maximum of the metabolic activity of the cells would be to precede, by a suitable interval, a maximum curative dose of X-rays

by a weak and stimulating one. Experiments of such a kind, however, belong to the province of the experimental biologist and pathologist, and not to the realm of the clinical electrotherapist.

Among experienced radiotherapists there is a general consensus of opinion that the harder the X-rays the better are the results. In fact, with the apparatus at our disposal not only is it impossible to get them too hard, but our failure to cure cancer, by means of X-rays, is due to our inability to obtain a sufficiently hard radiation by modern methods. For the past few years the demand for more powerful apparatus has been continually growing. At a recent conjoint meeting of the members of the Electrotherapeutic Section of the Royal Society of Medicine with the members of the Institute of Electrical Engineers, the discussion chiefly turned upon the possibility of realizing the ideal of radiotherapists, i. e. of obtaining an instrumentation capable of yielding X-rays of the hardness of the gamma rays of radium. There was no practical outcome from the meeting, one electrical engineer pointing out that, in the present state of our knowledge, the production of such an apparatus would cost several thousand pounds ; the instrument, when completed, would weigh several thousand tons, and would occupy a ground space little less than that needed for a general hospital.

A most interesting and instructive paper, communicated by Dr. Reginald Morton (2) to a meeting of the Electrotherapeutic Section of the Royal Society of Medicine, on the 17th December, 1920, tends to show the possibility of realizing our ideals in the cure of cancer by developments mainly in the construction of the X-ray tube.

The tube, with which Dr. Morton's paper deals, has been introduced by Dr. Hermann Wintz, the Professor of Gynæcology at the University of Erlangen, Bavaria. This tube is 30 inches long between terminals with a bulb 8 inches in diameter. Its regulation is carried out by

means of an Osmo regulator heated by an electrically controlled Bunsen burner. It is capable of working continuously for eight hours at a 16-inch spark gap, with 2·3 ma. passing through it. All the accessories, such as an iontoquantimeter to measure the radiation, and a sclerometer to measure the penetration, have been most carefully worked out, and are utilized with great precision.

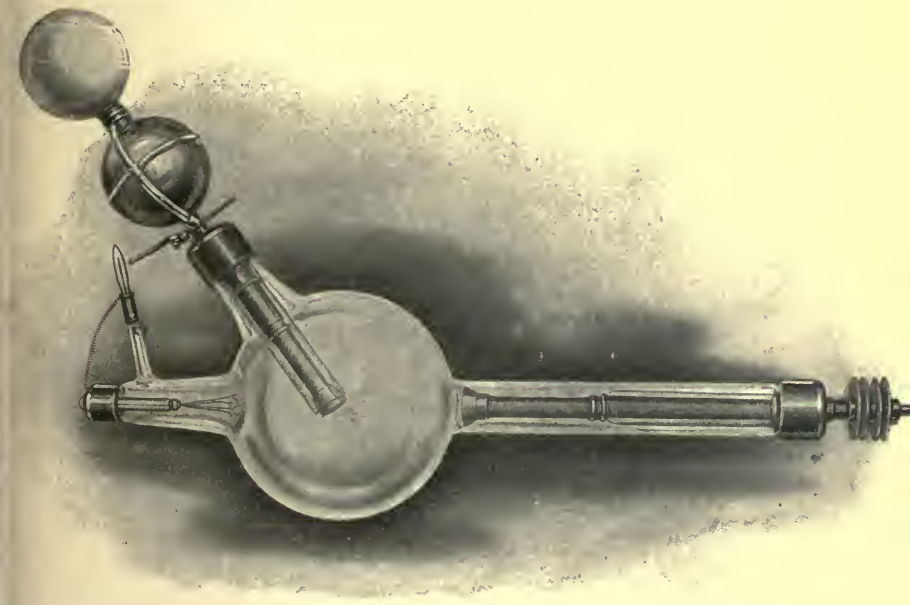

FIG. 19. The 'self-hardening water boiling' tube (the Wintz tube).

The object aimed at is to obtain as homogeneous a beam of radiation as possible, and this, with the heavy filtration employed of 12 mm. of aluminium, or 0·5 of zinc, is said to have been accomplished to an extent never before realized.

This tube, which is stated to have been found to be in practice 30 per cent. more efficient, and to yield a more homogeneous beam than the Coolidge tube, is worked

from a specially designed coil, employing a mercury interruptor.

The antikathode is water-cooled, fresh water being from time to time added to replace the loss which takes place from the water boiling when the tube is being operated : the tube is hence often spoken of as the ' self-hardening water boiling tube '.

The technique is such an elaborate and lengthy procedure as to remove it from the sphere of the ordinary electrotherapist, and to call for a specially qualified radiotherapist.

To obtain what is termed the ' Unit Skin Dose ' (U.S.D.), that is, the occurrence of redness of the skin in four to eight days, when employing a filtration of 12 mm. of aluminium, needs an exposure of thirty-five minutes at an antikathode distance from the skin of 35 cm., a spark gap of 16 inches, and 2·3 ma. passing through the tube.

Giving this U.S.D. the value of 100, it is stated that :

110 %	of the U.S.D.	would be	needed to	destroy cancer cells.
90 %	,,	,,	,,	paralyse cancer cells.
80 %	,,	,,	,,	destroy sarcoma cells.
50 %	,,	,,	,,	cure tuberculous joints and glands.
35 %	,,	,,	,,	treat effectively uterine fibroids, the radiation being applied to the ovaries.[1]

The effect of 40 per cent. of the U.S.D. on cancer cells was found to be a stimulating one, and under such a radiation the neoplasms were found to grow rapidly.

This calculation is of great interest and value as it tends to explain why, by our present methods, we are able to deal successfully, by means of X-rays, with skin diseases, glandular diseases, fibroids, etc., and yet have hitherto been unable to obtain good results in the radiotherapy of cancer. In the treatment of carcinoma of the cervix it was found that only 18 per cent. of the U.S.D. reached

[1] Injury to the large intestines commences at 135% of the unit skin dose.

the cervix, so the treatment was administered from six different ports of entry, each treatment being administered for thirty-five minutes, all six treatments being given on the same day : a fat person received an extra thirty-five minutes' treatment through the vagina.

The results of this treatment were that, after the parts had healed, no cancer cells could be detected in specimens excised from the cervix ; and of the first twenty-four cases treated by Dr. Wintz in 1918 twenty were reported as having no sign of recurrence two years later.

The treatment of carcinoma of the breast is an even more lengthy procedure ; a day's treatment of such a case comprises the following :

324 minutes' exposure at a focal skin distance of 70 cm., 59 minutes' exposure to the axilla at 30 cm. distance, 59 minutes' exposure to the clavicular region at 30 cm. distance. A total of 7 hours 22 minutes exposure in one day !

Six weeks is allowed for the blood and tissues to recover from the effect upon them of this radiation, and then an exposure of 5 hours 48 minutes is given at a distance of 65 cm. to the whole chest with the arm raised.

The results obtained appear to justify this drastic radiation, for it is stated that 75 per cent. of the cases treated by this method in 1917, without previous surgical operation, had been clinically cured.

Not only is the duration of the treatment increased out of all proportion to the duration of the radiations formerly employed, but, by nearly doubling the spark gap, the energy with which the electrons are hurled against the antikathode is enormously increased, and the frequency, hardness, or penetration of the resulting X-rays are correspondingly augmented,[1] since ' the upper limit

[1] The wave length of the most penetrating radiation obtainable from the Wintz tube does not at present appear to have been ascertained. Wintz, in his book, somewhat vaguely states : ' The radiation which we employ is in the region of the softest gamma rays of radium.'

of the frequencies is always proportional to the energy of the electron, and, therefore, to the potential imposed on the tube ' (Bragg). If the claims made for Dr. Wintz's method are justified it will be necessary to readjust our views in regard to the incurability of cancer by radiant energy alone.

It does not by any means follow that, though the Wintz method may be the best, or even though it may come to be regarded as the only justifiable method of radio-therapy for malignant growths, that it is therefore the most suitable form of radiotherapy for non-malignant conditions. Nor is this method necessarily at variance, though at first sight it might appear to be so, with the views and theories of Dr. Regaud. When dealing with a malignant growth, the advisability of simultaneously, if possible, destroying all the cancer cells, so that none may be left to increase and take root in the interval between a divided treatment, is at once apparent. But when dealing with non-malignant cases, such for instance as exophthalmic goitre, where the object is to diminish the hyperactivity of a hypertrophied and peculiarly radio-sensitive gland, the same immediate urgency does not exist.

Moreover, this therapeutic necessity for a single dose in malignant disease may be the explanation of the fact that more than double the dose is needed in the treatment of cancer cells, owing to the fact that they have to be treated at all stages of metabolic activity : whereas, in non-malignant cases, the urgency being less, the treatment may be given in divided doses permitting the cells to be caught at a period of maximum radio-sensibility, in which state a considerably smaller dose will produce the desired result.

With the horrible fear and dread inspired by malignancy, patients suffering from such a condition will no doubt cheerfully submit, buoyed up with the hope of a probable cure, to the discomfort, probably amounting

to real suffering, entailed by an exposure to X-rays of over seven hours' duration in one day ; and the resulting constitutional disturbance, which necessarily follows such an heroic radiation, will be incurred without hesitation, if the results from Dr. Wintz's method are such as are described.

The Wintz method enables very heavy filtration to be employed, and at the same time permits the administration of a lethal radiation to the deeply seated neoplasms.

It is this heavy filtration which permits a more or less homogeneous beam of hard, penetrative, and ' selective ' radiation to be obtained. With no filtration the beam consists of a heterogeneous collection of radiation varying from the softest X-rays to that of the hardest that the energy of the electrons emitted from the kathode of the tube permit. The general caustic and non-selective destruction of the skin and superficial tissues which resulted in such disastrous results in the early days of radiography and radiotherapy, was the result of the absorption by the superficial tissues of large quantities of soft radiation which in present-day practice are absorbed by filtration.

The heavier the filtration, the more will the soft rays be absorbed, and consequently the less will the skin be affected. But even with the thickest filter there will still be a residual minimum of soft rays to pass through it to the skin, and that is the reason why with the heavy filtration of 0·5 mm. of zinc employed with the Wintz method, sufficient soft rays pass through the filter to produce an erythema in four to eight days, and pigmentation of the skin in three to four weeks.

The therapeutic action of X-rays, when applied for the treatment of such conditions as chronic eczema, would appear to be a stimulating one, due to the erythema that it excites : for it is usually stated that the best results are not obtained in such conditions unless a definite erythema appears. Such an action is similar to, but

more intensive than, that obtained from ultra-violet radiation.

In the treatment of exophthalmic goitre the effect of the radiation is to restrain or diminish the secretion of the hypertrophied and over-active gland : in such a case the action of the radiation is a restraining or inhibiting one. In the case of cancer, the object aimed at is complete cell destruction. Thus in clinical practice we employ X-rays for three distinct purposes : (1) for stimulation ; (2) for inhibition or restraint ; (3) for the complete destruction of cells. These three objects are achieved by variations in the duration and energy of the radiations.

As in the case of ultra-violet radiation, we are led to conclude that the therapeutic effects of X-rays are due to the action of the radiation in splitting up the extremely radio-sensitive chromatin of the nuclei of the tissue cells ; that, as the result of this disintegration, a toxin or ferment is formed which, in proportion to the X-ray dosage, exercises either a stimulating, or inhibiting, or a destructive action.

The experiments of Curshmann and Gaupp (3) in leukæmia clearly show that such a toxin (a leucolysin) is produced as the result of the radiation from an X-ray tube.

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PART III

ELECTRO-DIAGNOSIS

CHAPTER I

THE ELECTRO-DIAGNOSIS OF PERIPHERAL NERVE LESIONS

During the late war the electro-diagnosis of peripheral nerve lesions formed an exceedingly important and interesting part of the work of the electrotherapist. It should always be borne in mind that this method forms only one of the links in the chain of evidence by which peripheral nerve lesions are detected; and, though it is one of the most important links, it must invariably be connected in the examination of a wounded limb with the other clinical methods; such as careful inspection of the limb to ascertain the nature, situation, and direction of all the wounds; observation of the temperature of the limb, the condition of the circulation and the nutrition of the skin, and the power of voluntary movement in the muscles; palpation of the muscle tone; and, above all, the examination for the presence or absence of fourmillement.

Fourmillement is that sensation of tingling or of pins and needles which is experienced by a patient in the peripheral distribution of a nerve when digital pressure is applied to the trunk below the seat of injury. Two precautions are necessary in eliciting this sign: the pressure must be applied below the lesion and not on the scar; the application must be such a distance below the scar that it can exercise no traction upon it. No leading questions must be put to the patient to suggest the nature of the sensation which he may feel, but, applying pressure at a suitable point, the examiner should merely ask the

patient, 'Do you feel anything?' If he merely replies that he feels the pressure of the doctor's fingers, the evidence is negative. If, on the other hand, he replies that he feels a sensation like an electric shock, etc., down his fingers or toes, as the case may be, and if the sensation corresponds with the anatomical distribution of the particular nerve trunk under examination, it may then be safely concluded that, either there still exist some intact axis cylinders, or that the nerve is undergoing the process of regeneration. In the latter case it is one of the first of the signs of regeneration to make its appearance.

The special value of the electrical tests is that they afford objective evidence in place of the subjective signs afforded by the other methods of observation. We may suspect, from the appearance of the skin and from the tone of the muscles, that the loss of voluntary power in a limb is only functional; but a very brief examination of the muscles of this limb by the faradic current will definitely prove to us, if the muscles contract, that the case is a functional one; and, if no contraction is elicited that there is an organic nerve lesion.

There are only two very rare and almost negligible exceptions to the above rule; it may, in rare cases, happen that excitation of the nerve above the lesion excites no contraction, but that excitation of the nerve below the lesion excites a faint contraction. This may occur in very recent cases of injury, where sufficient time has not elapsed for the peripheral fibres to degenerate completely, or it may possibly occur in slight cases of nerve compression, such as Erb's paralysis of the musculo-spiral nerve from slight compression. The errors likely to arise from these rare exceptions can be readily guarded against.

Electro-diagnosis by the faradic current was originally introduced by Duchenne, of Boulogne, in 1849, and, in spite of all the clinical and laboratory research which has been conducted since that time, it still remains the most valuable of all the methods at our disposal. The faradic

current demonstrates the condition of the nerve. When using the ordinary faradic coil the current is not of sufficient duration to excite a contraction in the more slowly acting muscle, if its nerve has been severely injured. As Adrian and others have shown, the mechanism by which a nerve is excited is a quick one, 1/1,500 sec. or less, and the mechanism by which a muscle is excited is a comparatively slow one, 1/100 sec. or longer. An ordinary faradic coil of the clinical type imparts a stimulus with a time duration of about 1/1,000 sec.; this is of long enough duration to excite a contraction when applied through the quick mechanism of the nerve, but it is not of sufficient duration to excite the more sluggish muscle deprived of its nerve. These observations only apply when using faradic coils of the ordinary clinical type; it is possible by using the enormous voltage obtainable from a powerful X-ray coil to excite a contraction in a denervated muscle.

When a muscle fails to react to the ordinary faradic current, we conclude that its nerve is not functioning; it may be completely divided, or it may be compressed by fibrous tissue, scar tissue, or callus, or it may be temporarily injured by external pressure, as in Erb's paralysis, or by being nipped by forceps during an operation.

If no contraction results from stimulation of the nerve or muscle by the faradic current, resort is made to the galvanic current to ascertain the condition of the muscle.

A healthy muscle with intact nerve supply will contract to a galvanic current strength of 1 or 2 ma. A muscle with its nerve supply injured may at first react to a stimulus of 3 or 4 ma.; as time goes on, if its nutrition is not fully maintained by suitable electrical treatment, it will require larger and larger stimuli, 7, 15, or 20 ma., and may finally reach a condition in which the muscle substance, having entirely lost its contractility, becomes fibrosed and will not react to any electrical stimulation.

The terms, partial R.D., complete R.D., introduced by

Erb, have for a long time been in common use. Partial R.D., or, to express the term fully, partial reaction of degeneration, includes those cases in which there exist diminished faradic and galvanic excitability of the nerve, diminished faradic excitability of the muscle, and there may exist either galvanic hypo- or hyper-excitability of the muscle.

The complete reaction of degeneration is distinguished by complete loss of faradic and galvanic excitability of the nerve, complete faradic inexcitability of the muscle, and usually marked by diminished galvanic excitability of the muscle. In testing the galvanic excitability the motor point is found to be displaced towards the tendon, the so-called longitudinal reaction, or, less correctly, the displacement of the motor point.

By far the most important of the electrical signs of complete R.D. is the alteration in the character of the contraction, the sharp and brisk contraction of the normal muscle giving place to a slow sluggish contraction, in some cases almost vermicular in character.

Apart from the fact that these terms of partial and complete R.D. have for so long been generally accepted, there is little to recommend their retention, for they are very indefinite and inaccurate. If, however, they are adopted, the term Absolute R.D. should be added. The term has a very definite and exact meaning ; it is applied to those cases in which the function of the nerve has been completely destroyed and the muscle tissue has been so injured, or has so completely degenerated into fibrous tissue, that it has lost all its contractility and is inexcitable by any form of electrical stimulation.

It has been the custom to include the so-called sign of Polar Inversion among the indications of complete R.D. In a muscle with intact nerve supply, a contraction is most readily obtained with the galvanic current at the make or closing of the current with the negative or kathodal electrode, K.C.C. ; at the break or opening of the current,

a strength eight or nine times as great is required in order to excite a contraction, and in this case the contraction is more readily obtained at the positive pole or anode, A.O.C. These results are expressed in the following formula :

$$K.C.C. > A.C.C. > A.O.C. > K.O.C.$$

It has been demonstrated by the experiments of Cardot and Laugier (*Journal de Physiologie et de Pathologie générale*, 1912) on the sciatic nerve and gastrocnemius of the frog, and by the observations of Bourguignon (*Revue Neurologique*, April 30, 1914) on human nerves and muscles, that at the make of the current it is the negative pole which is alone active, and at the break of the current it is the positive pole only which excites contraction. The so-called A.C.C. is a ' virtual ' K.C.C. situated deeply in the tissues or the substance of the muscle, and the so-called K.O.C. is a ' virtual ' A.O.C. similarly located.

At first sight it might seem to be possible to ascertain the degree of degeneration which had taken place in a muscle from the number of milliamperes required to excite a contraction. Unfortunately, this simple method will not give accurate information of this kind, owing to the varying factors, such as alterations in the dryness and thickness of the skin, etc., which nullify the value of such a calculation.

The limitations of these methods have induced physiologists to seek for a more accurate and definite technique. As the result of the work of the French physiologist, Lapicque, and the researches of Keith Lucas and others in England, this has been found by ascertaining the quickness of excitability.

To find the chronaxie of a nerve or muscle, the weakest strength of current, without regard to its duration, which will produce the faintest perceptible contraction is first ascertained. This strength of current forms what is termed ' the threshold of excitation ' or ' the single Rheobase '.

Physiologists, in order to make their results more accurate, double this strength of current, thus obtaining what is termed the double rheobase. No calculations are based on the strength of this current ; it is simply given the value of 10, and the further strengths employed are multiples of this number. In this way the errors, due to variation in skin resistance, which prevent accuracy in the ordinary methods, are obviated.

The next step is to ascertain by means of the Keith Lucas pendulum, Lapicque chronaximeter, or other instrument capable of measuring minute fractions of a second, the minimum duration of time which is required to excite a contraction with this strength of the double rheobase. This time, expressed in fractions of a second, forms the chronaxie of Lapicque for the nerve or muscle under examination. It will thus be seen that the chronaxie is concerned with two factors, the strength of the stimulus and its duration.

It is evident that a current must have a certain minimal strength or it will not excite a contraction ; it must also have a certain minimal duration, below which a current of a given strength will not excite a contraction. If the minimum duration during which a current of a certain strength will produce a contraction is reduced, no contraction will result unless the strength of the current is increased ; and, as the duration is decreased, the strength has to be increased in a rapidly increasing ratio.

The chronaxie of Lapicque is only concerned with weak currents. By this method it has been found that an uninjured nerve excites a contraction in its muscle with a current lasting only from about 1/1,500 to 1/2,000 of a second ; a denervated muscle will require a stimulus lasting 1/100 of a second, and as degeneration advances in the muscle this period will be increased to perhaps 1/20 or 1/10 of a second. There is therefore a very considerable difference between the chronaxie of the nerve and the muscle ; and this difference explains why an

ordinary faradic coil, the duration of the stimulus from which is about 1/1,000 of a second, will excite a contraction when the nerve is uninjured, but will not do so when it is not functioning.

If the strength of the stimulus is enormously increased, as for instance by the use of an X-ray coil or by a spark from a powerful static machine, a contraction can be excited even in a paralysed muscle by a current of very brief duration, 1/1,000 second or less. Such currents are not used in clinical work as their application is too painful. By further reducing the period of the stimulus, a period is at length reached at which no contraction will occur, however strong the stimulus may be.

Adrian published in the *Archives of Radiology and Electrotherapy*, May 1917, a most instructive and original paper entitled 'Physiological Basis of Electrical Tests in Peripheral Nerve Injury'.

'Either by varying the current strength and finding the least effective duration corresponding to each strength, or else by varying the duration and finding the least effective strength,' he was able to plot out a series of curves, which yielded most valuable and significant results.

He obtained three types of curves: C, the simple curve with short chronaxie of intact nerve and muscle; A, the simple curve with long chronaxie of denervated muscle; and B, a complex curve, 'made up of a steep, sharply bent curve when the current strength is high and the duration short, and a slower and more gradual curve when the duration is longer and the strength less.'

The steep, sharply bent curve of brief duration obtained with high current strength occurs only in the process of nerve degeneration or regeneration. When the nerve has fully degenerated, only the slow and gradual curve is found.

The sharply bent curve relates to the chronaxie of the nerve, the gradual curve to the chronaxie of the muscle.

There are no intermediate curves. 'We must conclude, therefore, that there is no gradual transition from the rapid to the slow curve as the nerve degenerates. Instead of this we have a period in which both curves are found together, and the transition consists in one curve becoming more and more prominent to the exclusion of the other.'

Adrian gives in his paper an exceedingly interesting

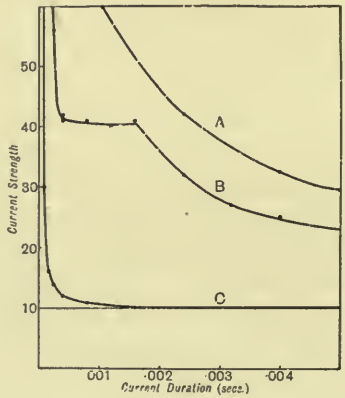

FIG. 20. Diagram to illustrate Adrian's Curves.
Reaction of Tibialis Anticus :
A. After complete division of the Sciatic.
B. Recovering from Acute Anterior Poliomyelitis.
C. With intact nerve supply.

and instructive series of curves, taken at twelve intervals from the third to the sixtieth day, of the reactions of the Orbicularis Palpebrarum in a case of peripheral facial paralysis (Fig. 21). He thus describes the changes in the curves :

'During the first eight days after the loss of voluntary power the curve remains absolutely unchanged. On the twelfth day a double curve is obtained, the discontinuity occurring when the strength is 20. On the fifteenth day the rapid curve has been almost entirely replaced by the slow, but it is still possible to detect a break in the curve at a current strength of 50, and with greater strengths

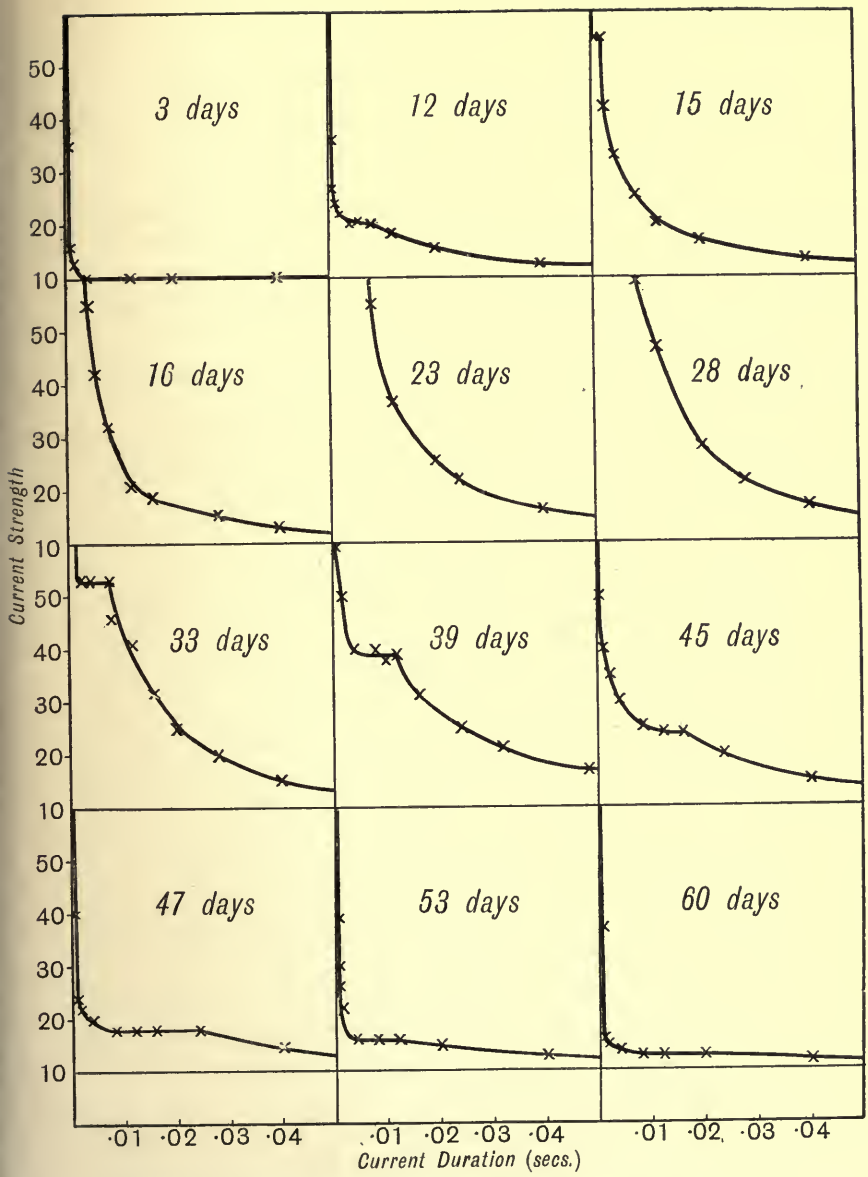

FIG. 21. Adrian's Curves of Facial Paralysis (peripheral). Reactions of Orbicularis Palpebrarum, from onset to recovery.

than this the curve is of the rapid type. On the sixteenth day no discontinuity can be found, and the curve is of the slow type throughout. The chronaxie of the slow curve becomes gradually longer and longer until the thirty-third day, when the rapid curve reappears at a current strength of 50. The first suggestion of returning voluntary power had appeared a day or two before, but it was not possible to say for certain that any power had returned until the thirty-fifth day. After the thirty-third day the rapid part of the curve reappears at weaker and weaker current strengths, and eventually it completely replaces the slow curve about sixty days after the onset of the paralysis.'

Unfortunately these methods, so valuable, so instructive, and so accurate, belong to the laboratory rather than to the bedside. Tinel, in his invaluable book, *Blessures des Nerfs*, referring to the simplified method of Lapicque, states: ' One must, nevertheless, confess that, even when simplified, these researches are always very long ; many hours are often necessary for the methodical examination of a single patient.'

After all, the value of these observations is physiological rather than clinical, for, as we have seen above, in the admirably worked out record of the course of degeneration and regeneration in the orbicularis palpebrarum, that ' the first suggestion of returning voluntary power had returned a day or two before ' any change in the electrical reactions, and that two days after the first electrical sign voluntary power was definitely present.

Two other methods have been devised for ascertaining the quickness of excitability of nerve and muscle: the method of Bourguignon and Laugier, and the condenser method of Lewis Jones and Cluzet.

The Method of Bourguignon and Laugier

This procedure is based upon the difference in character between the induced wave at the make and the induced

wave at break in an induction coil. The wave at make of the current causes self-induction in the coil, and this establishes a contra electro-motive force, which has the effect of weakening and lengthening the discharge. On the other hand, the wave at break sets up no self-induction and is consequently stronger and shorter in its discharge, provided a condenser is used to quench the spark at break, which would otherwise lengthen the wave. The healthy nerve and muscle, with their quicker chronaxie, are more adversely affected by this lengthening of the wave than the injured nerve and muscle of longer chronaxie. Hence the current at make will require a greater relative increase over the current at break to produce a contraction in a healthy than in an injured nerve and muscle.

By noting the degree of sheathing of the primary required to excite a contraction both at make and break, an index of excitability can be drawn up for any coil, but this index is only of value when it is used with the coil for which it was made.

This method has little practical value, for it involves most elaborate mathematical calculations, and the intensity of the stimuli required to excite a contraction at make causes far too much pain to render the method a popular one with patients.

The Condenser Method of Cluzet and Lewis Jones

This method, introduced into England by Lewis Jones, and into France by Cluzet shortly before the late war, seemed for a time likely to come into general use. The simplicity and neatness of the apparatus, and the painless character of the lower capacities, were strongly in its favour.

It was claimed by Lewis Jones that 'when the condenser method of testing has been further developed by clinical use, it will supersede the methods of testing now in vogue, and will enable electrical testing to provide

additional information as to the nerve and muscle in disease' (*Medical Electricity*, Lewis Jones, 1913). The use of the condenser, however, in England, appears to be already on the down grade, and many of those who were its most enthusiastic supporters are returning to the older methods. It was soon found that muscles in an advanced stage of degeneration, which were inexcitable by condenser discharges of high capacity, were still excitable by a galvanic current of easily tolerated intensity. It was indeed admitted by Cluzet that for testing very degenerated muscles the use of the galvanic current should be retained.

The ability to obtain comparative results from the observations of different workers was supposed to be one of the special advantages of this method, and Cluzet, with this object in view, laid down that the electrodes used should be of a standard size, the indifferent electrode 100 square cm., and the active one 1 square cm. Little attention has been paid to these necessary details, and still less attention has been paid in actual practice to the constant maintenance of the charging current at 100 volts, a most important factor if comparative results are to be obtained. It is very rarely that a condenser set is fitted with a voltmeter. It appears to be assumed that a town supply of nominally 100 volts remains constant at that tension, which is certainly not always the case.

In my experience it requires less time to find whether the nerve is excitable or not to the faradic current, and to ascertain the character of the muscular response to galvanism, than to find the minimum condenser capacity with which a minimal contraction is obtainable; and the information afforded by the former method is, in my opinion, more complete and precise than that obtained by the latter. By far the greatest objection, however, and the one which is inducing most workers to abandon condenser testing, is the very troublesome tendency of condenser stimuli to spread to the antagonistic muscles. In certain cases of infantile paralysis the relatively pain-

less character of the weaker condenser stimuli renders their employment a convenient method where the paralysis is not complete.

The above review of the various electrical tests shows that the old-established faradic and galvanic methods have not been superseded by any of the more modern procedures. The chronaxie method, in the hands of the physiologists, has been invaluable for demonstrating the physiological principles upon which the clinical reactions are based, but it is needlessly elaborate and far too lengthy a procedure for clinical purposes.

It is clear that the process of degeneration in a nerve is not of the same type as in a muscle. In a nerve the process is a sharply defined and an abrupt one; in a muscle it is a gradually progressive and slow process. In testing a nerve, the point to be determined is whether there exists continuity of axis cylinders to the end plate in the muscle; if this continuity exists, the nerve will react to appropriate stimulation. When this continuity is broken the excitability of the nerve suddenly ceases. In testing a muscle the question to be determined is an entirely different one; here it is not a definite question, 'Does continuity exist or not?' The question in this case is, 'What is the degree of excitability or contractility in the muscle?'

The faradic current will answer the first question by showing whether or not the nerve is excitable by faradic stimulation. The degree of excitability and contractility in the muscle will be demonstrated by the character of its response to galvanic stimulation.

Since the question to be answered is so different in the two cases, it is reasonable to adopt a different method in the two cases, rather than to attempt to show a gradual transition of combined improvement in the nerve and muscle which does not in reality exist.

The return of voluntary power appears to be equally as sudden and abrupt as the return of electrical excita-

bility in the nerve. 'It suddenly came like a shock,' one patient remarked to me, who, after many months of complete paralysis of the musculo-spiral nerve, made a complete recovery some weeks after his nerve had been freed by operation. 'The initial change always comes as a surprise to me,' an officer, suffering from a regenerating lesion of the brachial plexus, remarked to me when discussing the suddenness of return of voluntary power in the different muscles, as the nerve regenerated downwards.

In everyday practice it will be found that the combined faradic and galvanic methods will fulfil all essential requirements, but there is yet another method, which would appear to have a distinct value in certain cases, by affording a graphic record of the degenerative and regenerative changes in muscle. This process can also be used for ascertaining the degree of excitability in a nerve, but it is in relation to muscle testing that it appears to me to possess special importance. This is the graphic electro-diagnosis of Larat, fully described in *Traité pratique d'Electricité médicale*, by J. Larat, 1910, from which work the following extracts are taken.

Larat claims to have applied to clinical work the methods which previously had only been used in laboratories for experiments on animals. He designed an apparatus consisting of a circular band or bracelet, which was inexpansible except for about 3 cm. of its circumference, where a band of elastic was inserted. In this elastic an expansible rubber bulb was fixed, which communicated by a rubber tube to a tambour or drum. In connexion with this drum a stylet recorded the curves on a clockwork-driven cylinder. The speed of this cylinder was regulated to give a maximum rate of one revolution in twenty minutes. In its application the point was first ascertained, by the ordinary methods of testing, at which the muscle swelled most in contracting, and the bulb was then applied at this point. The stimula-

tion was next repeated, preferably by the bipolar method to obviate current spread as much as possible, and in this way a tracing of the contraction was obtained.

Larat insists on the importance of comparing a tracing from the sound side with one from the affected side. ' The value of the method depends on this comparison.' He claims that the personal factor of the observer is eliminated by this procedure, and that variations in the contraction so minute as to escape the eye of even a trained observer can in this way be delineated. He illustrates his work with a series of curves showing the rapid almost vertical rise and fall of healthy nerve and muscle, increasing in height and abruptness in hyper-excitability and with an increase in strength of stimulation. He shows the gradual, slight, and prolonged rise and fall of degenerated muscle, curves illustrative of various diseases, curves indicating the progress of recovery, curves of good prognosis and those of bad omen.

The delicacy and accuracy of this method should render it possible to obtain, from successive changes in the type of muscle curves, valuable information in regard to the prognosis, diagnosis, and treatment of nerve injuries. If the curve of a muscle with an injured nerve steadily improved in its type of contracture under electrical treatment, it would be an indication for the postponement of operative treatment. If the type of curve tended to lengthen and flatten in spite of all treatment, it would indicate the need for early operation. A rapid improvement would point to compression of the nerve rather than to section. Moreover, this method should yield a much-needed criterion of the relative value of various electrical and other physical methods.

Amidst the interest excited by the scientific methods of electrical tests there is a very real danger of losing sight of the special function of electro-diagnosis in peripheral nerve injuries. The main object of electrical testing is to enable the surgeon, from the report of the electrothera-

pist, to form as clear an opinion as possible of the condition of the nerve and muscle. In order to achieve this object the importance of adopting one universal and standard method of electrical testing cannot be too strongly emphasized. In the present state of our knowledge there can be no doubt that the method for universal adoption should be the combined galvanic and faradic method, which is both the simplest in practice and the one best understood by the surgeon. So far as time permits, there is no reason why the electrotherapist should not amplify, for his own records, the information thus obtained by the graphic or other method ; in fact, it is desirable that he should do so ; but the report to the surgeon should be as simple as possible. It should merely state in simple and clear language whether faradic reaction is present or not ; and, if the faradic reaction is absent, the character of the galvanic reaction should be given. The electrotherapist might also briefly state the conclusions which he draws from these observations in reference to the condition of the nerve and muscle.

The practice which exists in a few hospitals of allowing the nurse or masseuse to take the electrical reactions cannot be too strongly condemned ; conclusions based on such work are entirely valueless. To find the faradic reaction in a normal case is certainly an easy procedure, but it is often a most difficult matter to be certain of the absence of faradic reaction and to form a correct conclusion in regard to the condition of a muscle from the type of its contraction.

Only those with most experience fully realize how easy it is to make mistakes. As Zimmern and Perol remark (*Électrodiagnostic de guerre*) : ' C'est le médecin qui fait l'électrodiagnostic qui lui donne sa valeur.'

CHAPTER II

THE ELECTRO-DIAGNOSIS OF NERVOUS AND OTHER DISEASES

Apart from the electro-diagnosis of peripheral nerve lesions, information of value in the diagnosis of certain diseases of the nervous system may be obtained by electrical means. The following variations from the normal electrical excitability of nerves or muscles may occur. There may be faradic hyper-excitability or hypo-excitability, galvanic hyper-excitability or hypo-excitability. Or there may be inexcitability to any form of electrical stimulation.

A a general rule, where the tendon reflexes are increased, both galvanic and faradic hyper-excitability will be found.

Hyper-excitability to the faradic current will be found in cases of hemiplegia of recent occurrence, and in cases of tetanus and chorea.

Hyper-excitability to the galvanic current will exist in the early stages of hemiplegia, in tetanus, chorea, and in the initial stages of diseases of the spinal cord.

Hypo-excitability to the galvanic and faradic stimuli will be found in advanced cases of tabes and hemiplegia, in paralysis agitans, and in the later stages of many diseases of the spinal cord.

Complete electrical inexcitability occurs in severe and advanced cases of anterior poliomyelitis, in the Aran-Duchenne type of progressive muscular atrophy, in syringo-myelia, etc.

Different forms of special reactions are named after their various discoverers. In relation to the faradic current, there is the myasthenic reaction of Jolly, and also the myotonic reaction of Thomsen

In relation to the galvanic current, we have the reactions of Erb, Remak, and of Rich.

The two first named are the only ones we need consider. The myasthenic reaction of Jolly occurs in the disease myasthenia gravis, a disease which is characterized by the fatigue which supervenes when voluntary movement takes place in the muscles supplied by the motor nerves of the muscles of the eye, the facial, the hypoglossal, the glosso-pharyngeal, and the pneumogastric nerves. The contraction resulting from voluntary effort rapidly becomes weaker and weaker, gradually fades away, and no further contraction can be excited by voluntary effort until after a period of rest.

Corresponding phenomena are exhibited on faradic stimulation. The muscle contracts, then, in a few seconds, the contraction gradually fades away, although the stimulus is continued, and no further contraction can be excited until after a period of rest. The single shocks of the galvanic current, as interrupted by a metronome, are not sufficiently rapid to excite this phenomenon of fatigue, but it would doubtless be obtained from the use of the Leduc or Frimandeau currents. The reaction of Jolly has been experimentally produced by Marinesco in a healthy patient, by compressing the tested limb by an Esmarch bandage for half an hour previous to the experiment. In a modified form also this reaction is occasionally found in cases of Graves' disease, in some hysterical paralyses, etc., but not with the same distinctness nor to the same marked extent as it occurs in myasthenia gravis.

The myotonic reaction of Thomsen occurs in myotonia, or Thomsen's disease. This disease is characterized by tonic cramp of the muscles on attempting voluntary movement. 'The contraction which the patient wills is slowly accomplished; the relaxation which the patient wills is also slow' (Osler). This phenomenon is repeated in the contraction provoked by the faradic current. The muscle responds to a current of normal strength, but the

response is very slow, and is continued beyond the application of the stimulus, then slowly relaxes to quiescence. If a coil is employed, fitted with a trembler, the rate of interruption of which is adjustable, as in the Tripier coil, a rate of interruption, which is too slow to excite tetanus in normal muscles, will be found to excite a tetanic contraction in the muscles of a patient suffering from this disease. For though the stimuli are infrequent, they will, nevertheless, be sufficiently rapid to maintain the contraction in these slowly relaxing muscles.

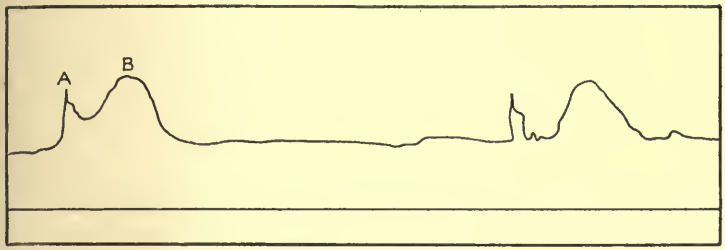

FIG. 22. Myograph of myotonic contraction showing A the primary and B the secondary contraction. (After Pansini.)

It will be seen that in these reactions we reproduce by electrical means the distinguishing features of the diseases in which they are applied.

This myotonic reaction to faradism has been termed the 'farado-tonic reaction'. There is also in myotonia a change in the reaction to galvanism; the resulting contraction in this case is tonic and is prolonged for a certain time after the cessation of the stimulus, 'the maintained galvano-tonic contraction' ('contraction galvano-tonique durable'). By means of myographic tracings Pansini (1) has shown that this maintained galvano-tonic contraction is made up of two secondary contractions, the first rapid, the second sluggish (Figs. 22, 23). Pansini's myographs show the first of these contractions with a rapid rise, a sharp peak, and a rapid decline; the second contraction is shown with a slow rise, a well-rounded peak, and

a slow decline. The first contraction, then, is of the type of a normal muscle reaction ; the second contraction is an abnormal one, slow in its rise, maintained for a time near its maximum, and slow in its decline. It is argued by Pansini and Babonneix that these two curves are due to the contraction of different substances, the first being due to the contraction of muscle fibres, the second to the excitation of sarcoplasm. In Fig. 22 the sharp rise of the

Fig. 23. Myograph showing a variety of the myotonic contraction, with the secondary contraction higher than the primary. (After Pansini.)

primary contraction A suggests the stimulation of the nerve; the gradual curve of the secondary contraction B suggests the occurrence of the direct stimulation of the muscle after the excitation of the nerve has ceased.

The maintained galvano-tonic contraction (the total myotonic contraction of Huet and Bourguignon) is found also in the muscular dystrophies ; but, in Thomsen's disease, the reaction is generalized throughout the muscles, and in the case of the dystrophies it is confined to a few muscles.

A non-maintained form of myotonic reaction (the partial myotonic reaction of Huet and Bourguignon) occurs in cases exhibiting the reaction of degeneration, and in the early stages of the muscular dystrophies.

Babonneix, to whose exhaustive and instructive paper (2), ' Le Syndrome électrique de la réaction myotonique ', I am much indebted for information on this subject, attributes the myotonic reaction in Thomsen's disease to the incomplete development of the sarcoplasm, which thereby retains indefinitely its embryonic character and is not converted into muscular fibres. He considers that the explanation of the myotonic reaction occurring in muscular dystrophies is not so clear, but thinks that the reaction in this case may be due to a destruction of the muscular fibres, or to an increase of the sarcoplasm cells.

Other forms of electro-diagnosis, which do not appear to have been studied in this country, are practised by the French electrotherapists.

Electro-diagnosis, based on voltaic vertigo, is employed in certain diseases.

The diagnosis is based on the following points : on whether the patient hears noises or bruits on the passage of a current through his ears, the moment at which he hears them, and in which ear. Attention is also paid to whether vertigo is produced ; if so, to which side the patient falls, or feels himself falling.

The technique of these tests appears to be troublesome, the information obtained thereby is very limited, and does not appear to be conclusive.

Electro-diagnosis in gynæcology depends on the relief or excitation of pain which follows the passage of faradic or galvanic current in the neighbourhood of the ovaries and uterus.

In the case of ovarian pains, if the passage of a faradic current removes or relieves the pain, its nature is assumed to be hysterical, and surgical intervention is contra-

indicated. If the pain is thereby unrelieved or increased, then the lesion is, except in rare cases, due to organic disease of the ovaries, and surgical intervention is called for.

The galvanic current is applied by means of an intra-uterine electrode. The following are the conclusions which Apostoli deduced from this method :

1. Every uterus which readily tolerates a current of 100 to 150 ma. (a very large current !) is a tolerant and healthy uterus, the appendages of which are also healthy.

2. Every uterus which does not readily tolerate 50 ma., and which shows signs of inflammation after its application, is a uterus of which the appendages are open to suspicion.

3. If the uterus is intolerant of a current of 20 or 30 ma., or reacts after such an application, its periphery is seriously affected.

4. If 20 ma. are not tolerated, the annexes are too seriously affected to admit of their preservation.

5. If the intolerance to the current diminishes, operative treatment should be postponed, as it is either a case of hysteria or a case on the road to recovery.

Of course before making such examinations the possibility of pregnancy must be definitely eliminated.

The chief practical point which is made clear by these observations is the one which is pointed out later when dealing with intra-uterine galvanism in the treatment of endometritis, namely, that if a current of 30 ma. causes much pain, the electrical treatment should be discontinued, and the case handed over to a surgeon or gynæcologist.

The method of electro-diagnosis which is based on variations in the electrical resistance of the human body is an extremely difficult and complicated one ; moreover, the results obtained are neither free from doubt, nor of much value.

Valuable information can be obtained from the applica-

tion of the faradic current to cases of divided or ruptured muscles or tendons. By exciting a contraction by this means, it can be readily ascertained whether the tendon or muscle has been completely divided or ruptured, and also which muscles or tendons are so affected by an injury.

References

1. Pansini, *Sulla Malattia di Thomsen.* (D. Pasquale, Edit. Naples, 1907.)
2. Babonneix, 'Le Syndrome électrique de la réaction myotonique', *Archives d'Électricité Médicale*, February 10, February 25, and March 10, 1914.

PART IV

AN OUTLINE OF THE APPLICATION AND OF THE MODE OF ACTION OF ELECTRICITY IN CERTAIN DISEASED CONDITIONS

CHAPTER I

THE GENERAL PRINCIPLES OF ELECTROTHERAPY

The application of electricity as a curative agent appears to have been regarded in the past as a mysterious force only capable of administration in an empirical manner. During the past seventy-five years little change has occurred in the views held by the medical profession in regard to the value of electricity as a therapeutic agent, for the opinion expressed by Dr. Golding Bird, in delivering a course of lectures on 'Electricity and Galvanism' before the Royal College of Physicians, in 1847, still holds good; 'Electricity has been by no means fairly treated as a therapeutic agent; for it has either been exclusively referred to, when all other remedies have failed—in fact, often exclusively, or nearly so, in helpless cases—or its administration has been carelessly directed, and the mandate, "Let the patient be electrified," merely given, without reference to the manner, form, or mode of the remedy being for an instant taken into consideration.

'Conscientiously convinced that the agent in question is a no less energetic than valuable remedy in the treatment of disease, I feel most anxious to press its employment upon the practical physician, and to urge him to have recourse to it as a rational but fallible remedy, and not to regard it as one capable of effecting impossibilities.'

Electricity still remains a ' rational but fallible remedy ', and is still incapable of effecting impossibilities. But it is by no means an empirical remedy ; for its mode of action is far more capable of explanation and visualization than many forms of drug therapy. It has, except perhaps in the case of radiotherapy, no direct or specific action on disease ; for it merely supplies us with that energy or force from which, by means of suitable instrumentation and the correct methods, we obtain the therapeutic energy we require.

We have already seen in Part I of this work that, by means of the polar action of the galvanic current, we are able to destroy by electrolysis, and by the chemical action of the products of electrolysis, morbid growths, diseased membranes, etc. By means of the interpolar action of the galvanic current, we are able to increase the temperature, and hence the blood supply of the part treated, and in this way we are able beneficially to influence its nutrition.

By interrupting an electrical current in periods of low frequency, we induce a recurrent concentration of hydrogen ions, which may be utilized for the excitation of muscular contraction, thus enabling us to fulfil a frequently recurring indication in the treatment of such conditions as obesity, paresis, etc. Or, again, by the stimulus which such a recurrent hydrogen ion concentration imparts to the tissue cells, the vitality or metabolic activity of various parts of the body may be considerably increased.

By further increasing the frequency of the interruptions of the current, we ultimately reach a point where the hydrogen ion concentration is of such brief duration as to excite no other effects or sensation than the heat set up by the friction of the oscillations themselves. We are in this way furnished with a means for heating to any desired extent any part of the body to any depth required. The relaxation of spasm and tension resulting from this

thermal energy enables us thereby to relieve pain in any part of the body. Moreover, as the further indirect result of this heat energy, we have, in the application of diathermy, the means of increasing the activity of glands in various parts of the body. By the concentration of this heat on small areas we are enabled to destroy by heat coagulation any growth on the surface and in some of the orifices and passages of the body, without fear of either primary or secondary hæmorrhage resulting.

The enormously high voltage obtained from the static machine enables us to excite, with an extremely minute milliamperage, powerful, pervading, and painless muscular contractions capable of breaking down peri- or intra-muscular adhesions. The same high voltage applied to an insulated patient enables us to stimulate without any unpleasant sensation the skin over the whole body, and this stimulation of the skin leads to an increased secretion of adrenalin from the suprarenal glands and a consequent rise of blood pressure of the greatest value to many exhausted patients.

When we pass from current electricity to radiant energy, excited by electrical methods, we find that we have the means of heating the superficial parts of the body by radiant heat, thus increasing the action of the sweat glands and yielding indirectly other therapeutic results of considerable value.

By the use of ultra-violet radiation we can induce a lasting and intense hyperæmia of the superficial skin area which is of great service in the treatment of skin diseases due to faulty nutrition. By the application of X-rays or the gamma rays of radium we can diminish the action of overactive glands, or, by a more intensive use of this method, we can entirely destroy them. There is, moreover, reasonable ground for hope that a technique may be elaborated which will result in cure of cancer by radiotherapy.

The temporary increase in the radio-sensibility of cells

at the time when they are multiplying by the division of their nuclei confers upon radiotherapy a so-called 'selective' action on such growths as neoplasms, the cells of which are far more frequently in a state of nuclear division than the cells of more stable structures such as bones and muscles. It is only in such a sense that electrotherapy can be said to have a specific or direct action. Since, then, current electricity acts only indirectly by affording the means of producing chemical changes, heat, mechanical or other form of energy from the exercise of which certain effects follow, the question resolves itself into, not simply whether electricity is needed in such or such a condition, but whether the condition is of such a kind as will be benefited by an increased blood supply, increased nutrition, increased functional activity; and then, that problem being solved, whether electricity is or is not the most convenient, the most easily controlled, the most powerful and efficient method of producing such results. Many of these effects can doubtless be obtained, though in a far less effective degree, by other than electrical methods; in the same way that the explosive mixture in the cylinder of a motor-car can be ignited by 'tube ignition' instead of by electric ignition. And there still may be members of the medical profession who prefer the older methods of treatment, comparable to the tube ignition of the early motor-cars, to the modern and more efficient methods yielded by electrotherapy.

The electrotherapist is sometimes criticized because he concerns himself with such a large number of diseases. There is a type of medical man who would tolerate an electrotherapist who confined his activities to one or two diseases, but cannot understand how he can even profess to benefit such a large number of entirely different conditions. Such a man fails to realize the fundamental principle that electricity is not a specific for any one type of disease, but that it is capable of affording the means for benefiting a very wide range of conditions.

It is important, moreover, to realize that electrotherapy is not antagonistic to any other form of treatment; it needs the association of the bacteriologist and serum therapist, it can be usefully associated with rational drug therapy, it is an adjuvant rather than an antagonist to the surgeon, it is indispensible to the dermatologist, and most helpful to the gynæcologist.

Penetrating, as electricity does, into so many and varied branches of the medical profession, there is no training so essential to the electrotherapist as the diversified medical experience to be gained by no other means than by general practice. Specialists in some other branches of medicine can afford to dispense with such experience; but the specialist in electrotherapy who bases his work upon a knowledge of electricity rather than upon a knowledge of general medicine, will inevitably tend to become an electrician practising medicine, rather than, as unquestionably he should be, a medical man utilizing electricity to achieve a certain desired effect.

The successful administration of medical electricity demands a sound all-round knowledge of general medicine, combined with a knowledge of the action and mode of application of the various electrical methods: and of these two the former is infinitely the more important and more difficult to acquire.

REFERENCE

Golding Bird, *Electricity and Galvanism*, 1849.

CHAPTER II

DISEASES AND INJURIES OF THE MUSCLES, LIGAMENTS, AND JOINTS

Muscular wasting due to injury or disuse can, when the nerve supply is unaffected, be readily and quickly cured by electrical stimulation. That form of electrical stimulation should be selected which most painlessly and efficiently excites a contraction most closely resembling the physiological type. Such a contraction is of a tetanic character, and in most instances is most efficiently and most simply excited by the use of the faradic coil. The stimulus should be applied with even gradation from zero to maximum strength, and should alternate with periods of intermission to enable the muscle to rest between each stimulation. It should be maintained at its maximum strength for a short but definite period.

The best method of obtaining such a result is by means of the Bristow method of graduated contraction; this is achieved by gradually sheathing the core of a specially designed faradic coil with the operator's right hand—the strength of the current is thus gradually increased—whilst the operator's left hand applies the small active electrode to the muscle under treatment. At the same time, the left hand grips the treated muscle; in this way the operator appreciates the degree of the resulting contraction and can simultaneously sheathe with his right hand the core of the apparatus so as to produce the degree of contraction required. The core is allowed to remain at the maximum point of sheathing for a definite pause, and is then slowly and steadily withdrawn. This procedure is repeated twenty times or more a minute. The chief advantage of this method is that the type of contraction is at all times under the direct observation of the operator

and can so be regulated as to obtain the maximum efficiency of contraction, and above all the operator is enabled to appreciate at once from the weakening or flickering of the contraction if the muscle becomes over-fatigued. Unless it is properly applied by a skilled operator the Bristow method has no advantage over the mechanical interruptor, and it must be admitted that it is the exception to see it applied in the correct method laid down by Mr. Rowley Bristow.

The Bristow method applies specially to the stimulation of single muscles. For the simultaneous excitation of large groups of muscles, and where the requisite technical skill of the operator is lacking, better results will be obtained from a mechanical interruptor, which should be so constructed as to admit of a slow onset of the current, its maintenance at the maximum value for a brief period, a steady and slow decrease, and an adequate period of rest.

Treated by such methods, it is surprising how quickly a wasted and flabby muscle regains its bulk and tone. Perhaps this result is best seen in the treatment of the wasted muscles of the knee joint by the three-point method of stimulation in a case of displacement of the internal semilunar cartilage. Improvement in the tone of the three muscles treated, the vastus internus, the quadriceps extensor, and the tensor fasciæ femoris, is clearly apparent after a few treatments. The electrical development of these muscles in such cases affords an instance of the help which the electrotherapist is able to render the operating surgeon before and after the excision of the semilunar cartilage, the period of convalescence and the recovery of full mobility and strength in the affected joint being very favourably affected by the pre- and post-operative stimulation of the muscles round the joint.

Associated with massage, electrical stimulation by the simple faradic coil, suitably administered, is of the greatest

service in maintaining the nutrition of the muscles of the limbs and abdomen in many prolonged and exhausting illnesses. Go round the wards of any hospital you will, turn back the bedclothes and examine the legs of the patients who have been in the hospital for weeks; you will find the muscles of these limbs wasted, flabby, deficient in tone, and the skin harsh, dry, and scaly. By the easily learnt administration of the faradic battery, by rubbing of so simple and elementary a form as hardly to be worthy the name of massage, such conditions could readily be prevented and the patients' period of convalescence materially reduced. But the nurses' energies are directed rather to polishing the pots and pans in the ward than to maintaining the nutrition of the muscles of the patients.

Again, how little attention is paid to the massage and electrical stimulation of the abdominal muscles of the multiparous woman after childbirth; and yet, by the simplest methods, adopted for a short time each day, how much after-trouble in the form of uterine prolapse and intestinal stasis might be readily prevented. But perhaps such observations as these belong to the science of common sense rather than to that of medicine or surgery.

In the treatment of sprains and strains of muscles the value of electricity is quickly demonstrated. A severely sprained ankle, much swollen and bruised, and very painful, can often, provided that no bone has been fractured and no important ligament has been lacerated, be apparently restored by suitable electrical treatment to its normal condition with full restoration of mobility and function, and complete removal of pain in less than a week. The best way of producing such results is by means of the Morton wave current of the static machine. The method by which the cure is produced in such cases is perfectly clear. As the result of the injury, effusion takes place into the surrounding tissues of what John Hunter well termed 'coagulable lymph', and this fluid

as it coagulates binds together the ligaments and muscles to themselves and the surrounding tissue ; so that the least movement causes acute pain from the dragging on and the tearing of the adhesions so formed. The powerful muscular contractions elicited by the electrical stimuli enable the muscles to free themselves from the intra- and peri-muscular adhesions so formed, and, at the same time, by the auto-muscular massage resulting from such contractions, lead to the dispersion of the effused lymph. A preliminary application of diathermy appears appreciably to aid the treatment, probably by inducing a relaxation of the parts and a dilatation of the efferent channels.

It will be evident that, in order to obtain the best and most speedy results, treatment should be commenced as soon as possible after the receipt of the injury ; later, as the effusion becomes less and less fluid, the adhesions will become more and more firm as the effused lymph is more and more organized, until they finally become fibrous, and incurable ankylosis results. It is a sound rule to radiograph every sprain and strain in the neighbourhood of a bone or joint before the commencement of treatment : otherwise a time is bound to come when a fractured bone will be overlooked. Recently I was consulted by a patient with the view to the electrical treatment of what he described as a slight strain of the ankle, occasioned by a slight twist of his foot whilst playing lawn tennis. An examination of the injured part showed no sign of fracture, but a precautionary radiograph revealed a fracture of the fifth metatarsal bone. In the same week I was consulted by a cricketer, qualifying for an important match, for what he termed a slight sprain of his thumb occasioned by stopping a hard drive off his own bowling. A radiograph in this case showed a small piece of bone chipped off the metacarpal bone of the thumb, and therefore I was enabled to predict the occurrence of a certain amount of thickening, which otherwise might have been attributed to inefficient treatment.

Similar cases are of such constant occurrence in electrotherapeutic practice as to render a preliminary radiograph the first step to suitable treatment.

There is one other caution to be pointed out in the treatment of severe strains and sprains; although all swelling and all pain may have disappeared from the injured part at the end, or even before the end, of a week, the parts have not, nevertheless, regained their normal strength in that short period, and if too vigorous exercise, such as Rugby football, is too soon indulged in, a recurrence of the sprain may occur. The electrotherapist should point out this danger to the patient, and in such cases should advise three weeks or more avoidance of violent exercise; but, in the case of University athletes qualifying for a 'blue', he may rest assured that the risk, and not his advice, will be taken.

Traumatic synovitis of the knee joint is in some respects a similar condition. In recent cases the fluid can readily be removed from the joint by the Morton wave current. A rubber bandage is tightly applied round the knee so as to force the fluid as much as possible into the supra-patellar pouch, a small electrode is fastened over the vastus internus, and the Morton wave current is applied for twenty minutes. The powerful contractions, alternating with relaxation, excited in the quadriceps extensor group, exert such recurrent pressure on the synovial fluid, that after twenty minutes of this treatment it is usually very much reduced in amount and often completely absorbed. In a recent case with an acutely inflamed synovial membrane the fluid will generally reaccumulate by the next day; it can be redispersed by a similar treatment, and at the end of the week, in the majority of cases, there will be no excess of fluid in the joint. In order to obtain these results it is essential that the contents of the joint should be fluid, and that the quadriceps extensor should be well developed. In most of the old-standing cases from the front during the war

I found that this treatment had little effect, and I attributed its failure in such cases to the contents of the joint being semi-gelatinous. Some old-standing cases of hydrops articuli do remarkably well with this treatment; the following was one of the first cases of the kind that I treated.

The patient was a young undergraduate, who came to me in January 1914 for hydrops articuli in both knee-joints. He had spent the previous summer in a London hospital without receiving any benefit. During the October term he was unable to get about except in a bath-chair. When he came to consult me he was unable to stand without his splints and without the aid of sticks. The muscles of the thighs were very extensively wasted, the knees appearing as fusiform swellings. The joints had been aspirated, and the contents were found to be sterile. His treatment was divided into two stages: the first part on the Bergonié chair for the redevelopment of the wasted muscles by electrically provoked exercises; the second part, the excitation of the redeveloped muscles by the Morton wave current. At the end of sixteen treatments he was able to walk without the aid of a stick, to bicycle up hill, and for several miles on the level, and there was no excess of fluid in the joints. There was no relapse, except a slight one after an attack of measles during the Easter vacation. During the summer term I showed the case at a meeting of the Oxford Medical Society; he had been playing cricket in the afternoon, but no excess of fluid could be detected in the knee-joints. At the outbreak of war he was passed as medically fit, and, I regret to add, subsequently met his death in Gallipoli.

Many old-standing cases of ' water on the knee ' appear to be due to weakness or lack of tone in the muscles of the quadriceps extensor group; the intra-synovial pressure is in such cases lowered and the fluid consequently accumulates and persists. The clear indication for treatment in such cases is the redevelopment of the

weakened muscles, thus restoring the normal pressure within the joint and causing a disappearance of the excess of fluid. Electrical stimulation fulfils this indication far more effectually than any other method.

Tennis Elbow and Rider's Strain. Lacerations of tendons at the point of their origin or insertion, such as occur in tennis elbow or rider's strain, yield more rapidly to electrical treatment than to any other remedy.

Tennis elbow is usually caused by the sudden arrest of a heavy-headed racket at the completion of an overhead service. The strain of arresting the momentum of the racket falls upon the extensor tendons of the hand, wrist, and forearm at their common origin from the external condyle of the humerus.

Inflammation, effusion, pressure, pain, and limitation of movement result from the injury, and are often associated with a localized periostitis.

During the coal shortage occurring during the war and the coal strike I saw several cases of a similar nature in elderly men occasioned by chopping wood with a heavy hatchet or axe.

The effect of the electrical treatment of this condition is to relieve the pain by the decompressor action of diathermy, and to diffuse the effusion by means of static sparks localized on the affected area. The small area usually affected renders the greater density of the static sparks more efficient than the Morton wave current.

In rider's sprain, laceration of either the adductor magnus, brevis, or longus from the rami of the ischium and pubes may occur in hunting or from riding a restive horse ; it may also arise from a variety of other causes : one case of this kind which came under my care occurred in the bow oar of the University Eight when he was endeavouring to stop the rolling of the boat in rough water.

The treatment is the same as for tennis elbow, except that, the lesion being more diffused, the Morton wave current is usually to be preferred to static sparks.

The results obtained in the electrical treatment of rheumatism and rheumatoid arthritis will largely depend upon the duration of the trouble and upon its situation.

Some of the best results yielded by electrotherapy are obtained from the treatment of chronic rheumatism and early rheumatoid arthritis of the knee-joint ; the results obtained from the treatment of a similar condition of the hip-joint are by no means so good. The reason for this is very obvious ; in the case of the knee-joint we are able to arrange two pads of large size, one on either side of the joint, with the result that the lines of force of the current are concentrated, with but little diffusion, upon the diseased part. In the case of the hip-joint the lesion is more deeply situated, with the result that the current is widely diffused and cannot be concentrated on the affected area. If any satisfactory results are to be obtained from the treatment of rheumatic conditions of the hip-joint, they will only be obtained from treatments of long duration, high current intensity, and continued over a period of some months.

In an early case of rheumatoid arthritis of the knee-joint, my experience is that usually twelve treatments, of 60 to 80 ma. continuous current, administered for forty minutes through two laterally placed pads of about 7 inches by 5 inches, will result in a disappearance of the pain, a diminution of the peri-articular thickening, and a restoration of mobility and movement. If pain is a prominent symptom, a preliminary treatment with diathermy should be administered, the current intensity should be low, not exceeding one ampere, with the size of pad given above, and should be continued for twenty to thirty minutes. My most recent technique is to precede the galvanism by a current of diathermy of one ampere for five or ten minutes.

A relapse may usually be prevented by the application of another course of from six to twelve treatments at the end of six months.

If the disease is of old standing, with much thickening

of the joint, more than twelve treatments will be required ; and in really advanced cases the treatment should be continued for at least six months. When the pain is not acute each treatment should be followed by massage and movements of the joint : under no conditions can massage be performed more advantageously than after a prolonged treatment by intensive galvanism.

During the course of the electrical treatment there is no reason why any other form of treatment, whether by drugs or sera, should be discontinued. The electrical treatment is solely a local one, and in no way takes the place of constitutional measures. The only precaution to take is to avoid any application to the skin of the joint, which might interfere with the administration of the full strength of current.

In advanced cases of rheumatoid and osteo-arthritis I usually advise the patient to purchase a 20-cell dry battery, and to attend for a course of twelve treatments for the purpose of instruction in its self-administration, and then to continue the treatment himself for a period of at least six months. Even very advanced cases, in which I have adopted this course, have usually written enthusiastically after six months of self-administered treatment to say how greatly they have improved. This course is naturally not so satisfactory as keeping the patient under observation the whole time ; but there are many cases in which the choice only lies between the auto-administration of the treatment or no treatment at all.

Hands, wrists, elbows, feet, ankles, and knees readily admit of this treatment ; but, as has been pointed out already, it is more difficult to obtain sufficient concentration of current on the shoulder- and hip-joints.

Certain forms of myalgia yield very readily to the heat of diathermy or to the auto-muscular massage resulting from the Morton wave current. Lumbago is, I believe, now generally regarded as due to a hypertonicity of the lumbar muscles, excited by the presence of toxins or other morbid process.

This theory of hypertonicity explains the very striking results that are obtainable from such different forms of treatment as diathermy and the Morton wave current. Forty minutes of a diathermic current of 2·5 amperes, or twenty minutes of the Morton wave current, will usually remove entirely the pain and stiffness resulting from a recent attack of lumbago. There are, indeed, few conditions which enable an electrotherapist to impress his patient so quickly with the curative power of electricity as that of lumbago. It is easy to realize that the heat derived from forty minutes treatment with 2·5 amperes of diathermic current would be calculated to relax any muscular spasm due to such hypertonicity, and also the powerful contractions excited in the affected muscles by the Morton wave current would be calculated to overcome any rigidity due to a similar cause.

Recent cases of torticollis, of the spasmodic type, are often readily cured by diathermy ; but in the treatment of old-standing cases of torticollis, my failures have been more marked and far more numerous than my successes.

The swelling and induration of the legs, consequent upon phlebitis and other causes, is very amenable to electrical treatment. The best method in these cases is the sinusoidal current ; its strength should be sufficient to excite weak but perceptible contractions of the muscles ; it should be rhythmically surged with suitable interruptions. The legs should be placed in a leg bath with feet resting on the electrode. In addition to the effect of the muscular contractions there is a direct stimulation of all the tissue cells in the legs by the recurrent hydrogen ion concentration, and this no doubt contributes largely to the production of the excellent results obtained from this method of treatment.

Diathermy will quickly and with certainty relieve the acute pain of gout. We rarely see nowadays the old-fashioned typical and classical cases of this disease. I have, however, treated two such cases by electricity. The following case is typical of both : the patient,

a country squire with a personal and hereditary history of port-wine and gout, with thickened finger and toe joints, with frequent exfoliations of sodium biurate, was sent to me for electrical treatment to relieve the acute pain and swelling in his toes, feet, and ankle-joints, from which he was suffering. The patient had recently had a severe attack of gout attended by a high temperature, headache, general malaise, and constitutional symptoms. On the subsidence of the high temperature, and the disappearance of the general symptoms, swelling and very acute pain became localized in the ankles and feet and he consequently came immediately for electrical treatment. The pain was immediately and completely relieved by diathermy, but on returning home the general constitutional symptoms reappeared with high temperature.

Of course two such cases are insufficient to warrant any generalization, but the following explanation of the phenomenon recorded is tentatively suggested.

During the high temperature the uric acid was in solution in the blood stream and excited general symptoms : on a reduction of the temperature occurring, the uric acid crystallized out in the extremities where the circulation was least active and the temperature lowest, and, before its formation into the relatively inert sodium biurate, exercised a painful and irritating effect in those regions.

The heat from the diathermy redissolved the crystallizing uric acid, it was reabsorbed into the blood stream, and again excited constitutional symptoms.

The practical conclusion to be deduced from this reasoning is as follows : that diathermy acts so efficiently in the relief of gout that, when given immediately after an acute attack, it should be administered with caution, and its application should be combined with some form of treatment for the elimination or neutralization of the uric acid.

Reference

W. Rowley Bristow, *Treatment of Joint and Muscle Injuries.*

CHAPTER III

THE DISEASES AND INJURIES OF THE NERVOUS SYSTEM

ELECTRICITY is of very limited service in the treatment of diseases of cerebral origin; it may occasionally be of use in treating some of the sequelæ which arise from these diseases, but its action then is only symptomatic and indirect.

In diseases of the spinal cord electrotherapy is more likely to produce benefit, owing to the greater accessibility of the parts; but even here very little has been achieved at present, though there is reason to hope that such a disease as insular sclerosis may, with an improved technique, be favourably influenced by radiotherapy. It is in connexion with the peripheral nerves, both motor and sensory, that our work is mainly concerned.

The Electrical Treatment of Anterior Poliomyelitis and the Peripheral Lesions of Motor Nerves

These two forms of peripheral nerve lesions, though differing very widely in their pathological origin, nevertheless in reference to their treatment form an electrotherapeutic syndrome, and so can be most conveniently discussed together.

In the recent war the treatment of peripheral nerve lesions presented one of the most important problems, when considering the restoration of the disabled soldier to a life of functional usefulness. The enormous number of such injuries afforded those engaged in their treatment a practical experience never before approached. An experience such as this naturally led many of those not immovably obsessed by preconceived ideas to modify

considerably their former views. Personally, I must confess that, as the result of experience and observation, I have departed somewhat from the views I originally put forward. The line originally adopted in reference to the electrical treatment of peripheral nerve lesions was somewhat as follows: 'The function of a muscle is to contract; when the motor nerve is severed it is impossible for the patient to make it contract voluntarily. Consequently those muscles whose nerves have been divided are rendered functionless; they hang like hammocks from their attachments, waste and toxic products accumulate in their substance, fatty degeneration takes place, and finally, if untreated, conversion, more or less complete, into fibrous tissue occurs, so that by the time the nerve has regenerated, the muscle has lost all contractile power. Our object therefore in the treatment of paralysed muscles is to make them contract by means of the galvanic current, and so, by exercising their function, to maintain their contractility and nutrition while the nerve is undergoing the process of regeneration.'

Looking back on my war experience, I am inclined to think that there are two fallacies, at least, in this argument. The first fallacy is that one overlooks the difficulty, or even the impossibility, of exciting a really efficient contraction in a muscle, the nerve of which has been completely severed.

Experience shows us that the density of current needed to excite a contraction in such a muscle is very great, and that the resulting contraction is confined to a few fibres; such a contraction occurring with the single isolated shocks of the galvanic current can have but little influence on tissue drainage.

The second fallacy is that the maintenance of the muscle's condition is solely dependent, from the electrical point of view, on the excitation of contraction.

No doubt in treating such cases on the theory stated, and administering strong electrical currents to excite such

contractions, we did very considerably contribute to the maintenance of the muscle's condition ; but the greater part of such benefit was probably due to the heating effects of the current and the stimulating influence of the hydrogen ion concentration, which resulted from the use of interrupted galvanism of high intensity.

My more recent experience, the outcome of contrasting several cases of complete nerve lesion treated by different methods, is that the surged sinusoidal current, to the strength necessary to excite faint contractions in the neighbouring healthy muscles, yields the best results in these cases. It is probable that, obsessed by an orthopædic ukase, too much importance has been attached by electrotherapists to the idea that harm is done to the paralysed muscles by the over-action of the healthy muscles during electrical stimulation. The vigour of such contractions is not such as to lead to over-stretching, and the effect of the contraction of the healthy muscles is to bring an increased blood supply to the part. Certainly the faint tremor excited in the healthy muscles by a sinusoidal current of the strength advocated can have no such harmful action.

In the treatment of peripheral nerve injuries on the point of recovery, the proposition is an entirely different one. The period at which the end-plate is recovering is the time at which harmful fatigue of the nerve or its end plate is most easily produced, and it is very important that electrotherapists should fully realize this point. The teaching usually given is that as soon as a faint faradic response occurs in a formerly paralysed muscle the galvanic current should be abandoned for the faradic. Nothing is calculated to produce more harmful results at this period. At a time when the end-plate is most susceptible to fatigue, a stimulus occurring fifty times a second (the faradic) is suddenly substituted for one occurring only once or twice a second (the interrupted galvanic). This period of the recovery of the end-plate

is the time for the application of the Lapicque current, which stimulates, at a low intensity, single and isolated contractions in the recovering muscles without any contraction occurring in the neighbouring healthy muscles. The return to voluntary power is very much expedited by this method of Lapicque. Its beneficial action is largely due, I think, to the fact that the patient sees for himself the isolated contraction slowly occurring in the formerly paralysed muscle, and this materially assists him in applying voluntary effort to intensify or produce this movement.

The results obtained by the treatment of peripheral nerve lesions during the war clearly show that by suitable electrical treatment, not necessarily by the excitation of contractions, we are able to influence favourably the healing of the wound, to heal trophic sores, or to prevent their occurrence, to improve the condition of the skin, replacing the dry, harsh, scaly condition associated with untreated nerve lesions by a state more nearly resembling the normal, to aid the nutrition of the affected limb by increasing its temperature and accelerating its circulation, and thus, though we make no claim to affect directly the regeneration of the nerve, we must, nevertheless, indirectly influence that process by inducing in the limb a condition more favourable to regeneration.

These are not merely subjective symptoms favourably interpreted by too enthusiastic electrotherapists: actual measurements of the limbs showing increase in girth, reappearance of the growth of hair on the skin, the diminution in the milliamperage of the galvanic current required to excite a contraction, the increased formation of callus, in ununited fractures, radiographically demonstrated by Dr. Barclay as taking place after suitable electrical treatment, are objective signs which admit of no other interpretation than that the nutrition of the tissues, lowered by injury or disease, can be greatly improved by modern electrical methods.

The Electrical Treatment of Anterior Poliomyelitis (Infantile Paralysis)

Recent researches into the morbid anatomy of infantile paralysis have shown that 'we can no longer regard it as an affection limited to the anterior horns of the grey matter of the spinal cord, but a widespread polio-myelo-encephalitis with meningeal complications. The changes in the spinal cord are very characteristic. The meninges are moist, the pia is hyperæmic, sometimes with small capillary hæmorrhages. On section the cut section bulges, the grey matter is hyperæmic, appearing as a reddened H, or the redness is limited to the anterior horns, which may show spots of hæmorrhage' (Osler). The virus exciting these conditions belongs to the filterable class of micro-organisms, but has not yet been cultivated. How far the lesions of the anterior cornua are due to the direct action of the virus, or to the pressure occasioned by the engorgement of the subdural space, has not been determined. The treatment of the first or inflammatory stage of the disease should be one of decompression, that is to say, it should be directed to the relief and diminution of the subdural pressure. I have had no experience of the electrical treatment of this stage of the disease; and would only express the opinion that the methods advocated by some electrotherapists, the dilatation of the superficial vessels of the skin over the affected area by ultra-violet radiation, the decompressor action of X-rays, the relief of tension following the dilatation of the neighbouring vessels by diathermy, are based on sound and rational lines.

It is, however, with the after-effects of this pathological condition of the spinal cord that electrotherapy is chiefly concerned. The problem may be briefly stated as follows: that, either as the result of the subdural pressure, or as the result of the direct action of the virus, certain cells of the anterior cornua are affected to a varying extent. (1) Some are so severely affected that, no matter what treat-

ment is adopted, no benefit will result. (2) Some cells are so slightly influenced that complete recovery will take place whatever form of treatment is adopted, or even in spite of treatment. The first class of case belongs almost entirely to the orthopædist, whose function it will be to make the best of a very bad case. It is obvious that it makes very little difference into the hands of which class of legitimate practitioners the last-mentioned type falls. But between these two classes there is a very wide division, in which the number of cells, and the number of nerve filaments recovering, will depend upon the efficiency of the treatment adopted. The more efficient the early treatment by decompression, the fewer will be the cells destroyed : the more efficient the after-treatment by maintaining the nutrition of the paralysed limbs, the less will be the fibrotic changes in the muscles, and the more favourable will be the condition for the recovery of the nerve fibres in connexion with those nerve cells that have not been completely destroyed. It is with this intermediate class that electrotherapy is mainly concerned. The problem of the most efficient treatment of infantile paralysis in the chronic stage is practically identical with the treatment of peripheral nerve lesions. In both instances treatment which is conducive to the maintenance of the circulation in the affected limbs, prevents the occurrence of chilblains and trophic sores, preserves the temperature, and increases nutrition, will be calculated to prevent fibrotic changes in the paralysed muscles, and will tend to facilitate the regeneration of the nerve.

The indications for treatment are plainly shown by the cold, flabby, and wasted limbs, and by the chilblains and trophic sores by which they are often covered.

It is unfortunately true that many of the leading authorities on infantile paralysis attach little or no importance to the action of electricity in this disease. But such persons know little or nothing about electricity, and often less about its application to medicine. They may

sometimes admit that the faradic current will excite healthy muscles to contract and so may be of use in their development ; but they are often ignorant that the interrupted galvanic current is capable of exciting contractions in paralysed muscles. They are unaware of the true aims of electrical treatment and the methods by which these aims are realized. What little experience they may have had of its use is derived from ' treatments badly directed, badly applied by unqualified persons, from treatments of insufficient intensity and duration, and applied with defective instruments ' (Bergonié (1)).

It was to physicians of such a type that John Wesley (2) addressed his final appeal : ' That none of them would condemn they know not what : That they would hear the cause, before they pass Sentence : That they would not peremptorily pronounce against Electricity, while they know little or nothing about it. Rather let every candid Man take a little Pains, to understand the Question before he determines it.'

To be fully effective, any form of treatment for infantile paralysis must be based upon an accurate electro-diagnosis. With children, Bergonié's method of simplifying the technique by testing the whole limb at one time, as for instance in the leg, by applying one pad at the buttock and the other round the foot and ankle, will give sufficiently accurate information with a minimum of discomfort to the patient. The condenser method of testing, if the paralysis is not complete, will be more readily tolerated than the faradic and galvanic method. Where, however, the degree of degeneration is advanced, the large condenser stimuli required to excite a contraction will be found to be equally or even more painful than the galvanic.

An accurate electro-diagnosis enables an experienced electrotherapist to form a reliable prognosis, and he is able to predict from it, with reasonable accuracy, which muscles will improve and the extent to which they will recover their power. Such an examination affords the

only reliable grounds upon which to base the line of treatment. The form of treatment will necessarily be different for a muscle reacting to faradism from that required for one which only responds with a flicker to strong galvanic stimulation. The former if treated by faradism will readily and quickly improve and return to its normal condition.

In the latter case no hope of improvement can be entertained from the excitation of muscular contraction, and attention must be directed to the maintenance of the nutrition of the limb. For the avoidance of deformity such a case should be placed under the supervision of an orthopædic surgeon. Between these two degrees there is a wide range in the extent of disability found in cases of infantile paralysis, and only long experience will enable the electrotherapist to lay down the most suitable form of treatment and to predict its probable result.

There are one or two points which are especially noticeable in the electrical treatment of this disease. One of the most striking is the sudden improvement which almost invariably occurs shortly after the commencement of the treatment; it is almost as though there were some latent recovery lurking in the muscle needing only the electrical stimulus to reveal its presence. The hopes of the relatives are often unduly raised by such an occurrence, and expectations of a speedy cure are thereby entertained, which are incapable of realization. Such an occurrence is usually followed by a more or less prolonged interval in which little or no improvement takes place, and the hopes of the relatives become correspondingly depressed, and the patience of the electrotherapist is sorely tried. Then a faint flicker is suddenly detected in a previously inactive muscle, and is soon followed by a decisive contraction, so the hopes of the friends are again buoyed up. And so the case proceeds with alternations of hope and despair, but steadily progressing towards an increase in the number and power of the movements.

The progress of such a case is invariably slow; a treatment of at least an hour's duration daily may have to be persisted in, with short intervals of rest, for a period of two or three years. But the time, trouble, and expense are well repaid by the results ultimately obtained. The following is an actual and typical case. An adult with a history of an attack of acute anterior poliomyelitis eighteen months previously, improved at first, but for the past nine months there had been no improvement. The legs alone were affected, and their muscles showed all variations from complete galvanic inexcitability to the faradic reaction. The patient was unable to balance himself or to stand without the aid of crutches.

Under prolonged treatment by intensive electrotherapy, followed by massage and re-educative movements, the patient gradually improved: he was first able to discard his crutches, and balance himself with sticks; later at the end of eighteen months' treatment he was able to balance himself and walk for a short distance without sticks. All the muscles, however, have not recovered voluntary power at the end of two years, and in many of those which have recovered voluntary movement the power is not normal; but as the result of the treatment the best is made of the muscles that have regained their nerve power, and the others have been placed under the most favourable conditions for recovery. Contrast such a case with one treated by undue splintage and rest; and in the one case you will find a patient able to get about for himself, and in the other an invalid requiring the unremitting attention of a constant attendant.

One of the most important points relating to the effect of suitable electrical treatment in cases of infantile paralysis is that it develops to the full extent those muscles which regain their voluntary power.

Without the aid of electrotherapy the prognosis of infantile paralysis is as Bergonié says: 'toujours un avenir d'atrophie, de déformation des membres, d'appareils

orthopédiques indéfiniment renouvelés, que l'on prédit à ces petits malades ; en un mot : une vie d'infirme, d'éclopé ou de cul-de-jatte, avec, pour consolation, des remèdes auxquels on ne croit pas soi-même.'

Bergonié rightly goes on to point out that the prognosis and forecast of the result of the treatment depend upon the spirit which directs and the hand which applies it ; in the same way as in a severe operation, the prognosis depends to a large extent upon the operative technique and the manual skill of the operator.

The Electrical Treatment of Neuritis

No advantage is to be gained, from the point of view of treatment, by attempting to differentiate between neuralgia (pain in a nerve) and neuritis (inflammation of a nerve). Neuralgia has been defined as ' a painful affection of the nerves, due either to functional disturbance of their central or peripheral extremities, or to neuritis in their course ' (Osler).

The distinction between ' neuritis ' and ' neuralgia ' is largely an artificial or terminological one ; for if, as Weir Mitchell points out, the susceptibility to pressure in a nerve is due to irritation of its nervi nervorum, the ultimate cause of the pain from the pressure of a growth is associated with a neuritis of the nervi nervorum due to their irritation.

The treatment of neuritis practically resolves itself into the treatment of pain, for were there no pain, patients would not come to the electrotherapists for treatment of neuritis, and with very few exceptions this pain is the result of pressure.

So that the main object of the treatment is primarily the relief of pressure. The causal relationship of pressure to pain is well seen in the case of the pain of an abscess or toothache, and its immediate relief on the removal of the pressure by the evacuation of the abscess or the extraction of the offending tooth.

Pressure from a constricting band may in the same way cause severe pain, which immediately ceases on the removal of the constriction ; and probably there is no more terrible pain than that occasioned by the pressure of an aneurysm. Spasmodic pain is doubtless due to the tension or pressure excited by muscular contraction. It thus becomes evident that if the pressure occasioned by inflammation, or constriction, or by spasmodic muscular contraction is relieved, the pain will cease. Thus in the treatment of pain, the relief of abnormal pressure becomes the first aim of the electrotherapist. With this object in view, diathermy is an agent of the greatest value, for it readily overcomes muscular spasm by the heat which it generates, and also acts as a ' decompressor ' in diverting the excess of blood from an inflamed area into the surrounding heated tissues. The effect of such an action, which is both immediate and capable of application to any part of the body however deeply situated, renders diathermy the method of choice in dealing with acute and recent lesions.

In dealing with more chronic conditions where the pain is caused by the constriction or compression exercised by fibrous tissue, better results will probably be obtained by the slower but more lasting effects of intensive galvanism. It is probable that an increased leucocytosis occurs in such cases in consequence of the treatment, which assists in the resolution of the fibrous tissue exerting the pressure. This ' sclerolytic ' action is, however, a very limited one, and no very definite results can be hoped for from such treatment of large masses of fibrous tissue. An interesting case, showing the effect of pressure or constriction by fibrous tissue, occurred in my hospital practice during the war. A young soldier, enlisted solely for clerical work, was admitted to hospital complaining of severe and almost constant pain in the stump of his left leg which had been amputated for tubercular disease several years previously. The patient was evidently suffering from the pressure

effects on the end of his stump, occasioned by a badly fitting bucket peg leg. A variety of electrical treatments yielded no results beyond slight and temporary relief of pain.

I therefore sent the patient to the surgical department for the exploration of the long saphenous nerve, to the former distribution of which the pain had been referred and the stump of which was tender on pressure. The end of this nerve was found to be thickened, and on its removal was sent to the pathological department for examination: a report was returned to the effect that there was 'much fibrous thickening both in and around the nerve fibres'.

The pain was completely relieved for a short time; on its subsequent return a further length of the nerve was removed, after which the patient was permanently cured. In this case the continued irritation from an ill-fitting bucket leg had set up inflammation in the nerve, resulting in the formation of fibrous tissue for some distance in and around the nerve trunk. Radiotherapy was the only form of electrical treatment which would have held out any hope of success; but in view of the accessibility of the lesion, excision was undoubtedly the best treatment. This case also affords an explanation of the difficulty occasionally experienced in dealing with old-standing cases of sciatica and other forms of neuritis.

Cervical ribs may exist for years without giving rise to symptoms of neuritis, and then a sudden strain, such as the wrench of an arm in alighting from a tramcar, may set up a neuritis attended with great pain in the arm on the affected side.

This pain can be much relieved by diathermy, and the inflammation and thickening may disappear with rest, although the predisposing cause remains unaltered and may subsequently lead to a recurrence of the symptoms. The following case of a hospital sister, illustrated by a radiograph (Fig. 24), for which I am indebted to my

hospital colleague, Dr. Sankey, demonstrates this point. For as long as she can recollect, the patient has been unable to carry a heavy weight in either hand without exciting a feeling of discomfort in the arm employed. In 1917, after catching cold whilst bathing, she had a stiff

FIG. 24. Dr. Sankey's radiograph illustrating case of double cervical ribs.

and swollen neck, followed by her first attack of brachial neuritis. The left arm was the one affected on this occasion. The pain was acute for three weeks, but after a further period of complete rest for four weeks it cleared up. No recurrence of neuritis occurred until Christmas, 1920, when she wrenched her right arm severely in

working a lift. This strain was immediately followed by some pain consequent upon the initial bruising; but no pain typical of neuritis occurred for the first few days; then very severe pain of a definite neuritic type developed in the right arm and prevented her from sleeping. This pain was promptly relieved by diathermy, but invariably recurred upon the slightest use of the arm, and was only ultimately cured by a further period of complete rest.

Neuritis may arise from a variety of causes. (1) The rheumatic type, due to exposure to cold, damp, draughts, over-fatigue, or exertion. (2) The traumatic type, due to pressure, wounds, the lacerations accompanying dislocation or fracture, injection of alcohol, ether, etc. (3) From the extension of inflammation from neighbouring areas, as in caries of bone. (4) Secondary to the over-fatigue of central cells, as in occupational neuritis. (5) As the sequela of the action of the poisons of infectious diseases.

The prognosis of neuritis under electrical treatment depends upon the duration of the condition and upon the nature of the cause. A simple neuritis due to over-exertion or exposure to cold will in the majority of cases quickly yield to suitably applied diathermy. On the other hand, no expectation of a permanent cure of neuritis due to extension from diseased bone, etc., can be entertained until the cause of the trouble has been removed. It is probable that more speedy cures will result when the inflammatory condition is peri-neural than when it is interstitial or between the nerve bundles. An accurate diagnosis, not only of the cause but of the exact situation of the lesion, is essential to successful treatment. In brachial neuritis, for instance, the location of the pain is very rarely the situation of the lesion, and to apply diathermy, as is so often done, through the painful area, is likely to produce no benefit.

In the majority of cases of brachial neuritis due to cold or exposure, the lesion is, I believe, in the cervical region, and is probably the result of pressure on the inflamed

and swollen nerve trunk as it passes through the unyielding inter-vertebral foramina. In these cases the pain is referred to the distribution of the fibres so compressed. Often in cases of brachial neuritis a history can be obtained of a previous stiff neck; but the most suggestive evidence in favour of this view is obtained during the application of diathermy. The immediate effect of diathermy, especially if it is administered to nearly the limit of safety, is often to cause temporarily an actual increase in the pain. This is probably due to an initial increase in the tension in the part itself due to the heat, before the surrounding tissues become relaxed. This initial exacerbation of pain, which is of good omen as showing that the electrodes are applied over the right area, quickly passes away.

Now, when the electrodes are applied on either side of the neck and the diathermy current transmitted transversely through the cervical vertebræ, the first effect of the treatment is often to excite an increase of the pain in the arm at the usual painful spots, such as the elbow, etc. As these areas are in no way directly affected by the application of the current in such a direction, the pain in the arm must be referred, from the heated nerve trunk in the neck, to its peripheral distribution.

This theory of the ' radicular ' origin of brachial neuritis is further supported by the fact that the best results are obtained in this condition by the treatment of that area. At the time I came to these conclusions I was not aware that the French electrotherapists had already arrived at a like conclusion in relation to the radiotherapy of sciatica, and that they had pointed out that the radicular area, the lumbo-sacral region, was the part on which the radiation should be applied in the treatment of that disease.

The special importance of the cervical region applies to cases of neuritis, arising from exposure to colds, draughts, and damp. In the treatment of the traumatic variety, an accurate history of the nature of the injury

and the situation of the lesion are of primary importance.

In all cases of injury a radiograph should be taken, and a similar precaution should be taken whenever, from the unyielding nature of the case to treatment, or from a history of the onset following a strain, or in cases where there has been previous discomfort in the use of the arm, there is reason to suspect the presence of a cervical rib or band.

Neuritis of special regions presents points of special importance.

Brachial Neuritis. The main points to be considered in this location have already been discussed. The following is a good routine treatment in a case which presents no special features.

Electrodes 10 cm. × 5 cm. are applied and held in position by the operator on either side of the neck, and a current of about 0·9 to 1 ampere administered for ten minutes. One of the electrodes is then bandaged to the extensor surface of the flexed forearm, immediately below the elbow-joint, the other electrode is held over the lower cervical and upper dorsal spines, rather to the opposite side to that of the affected arm, and a current of about 1 ampere, varying slightly in degree with the diameter of the arm, is passed for five minutes. Next the electrode at the elbow-joint is changed for a hand electrode which is held in the hand of the affected side, whilst a current of 0·5 ampere is passed for five minutes, or until the heat at the wrist-joint becomes too great to be tolerated without discomfort. In this manner the nerve is treated throughout its whole length, and in each of the three applications the cervical region receives a treatment. The application of diathermy may be followed by the static breeze, the high-frequency *effluve*, or the ultra-violet light ; each of these owes any benefit it may produce to the counter-irritation which it excites.

Where the patient is much exhausted from the constant

pain, or where there has been much sleeplessness, much benefit will usually be obtained from the static charge. This treatment is especially useful when the more acute symptoms have passed away.

In old-standing cases of brachial neuritis the best results may be sometimes obtained from the more slowly acting, but more lasting, action of intensive galvanism. A thick pad, about 7 inches × 5 inches, is bandaged to the back with its centre over the spine of the seventh cervical vertebra, the affected arm is placed in an arm bath, and a constant current of 40 to 60 ma. is passed for forty minutes or more.

Often this treatment may be advantageously preceded by a diathermic current to a comfortable intensity of warmth, passed through the same rheophores and pads for ten minutes prior to the application of the galvanism. In very old-standing cases the best results will be obtained from the radiotherapy with a penetrating radiation over the lower cervical and upper dorsal vertebræ administered in the manner described below in the treatment of sciatica.

Sciatica. This term is usually applied to cover such a variety of conditions that, as ordinarily used, it connotes little more than ' pain in the neighbourhood of the leg '. At a very short interval two patients, the one a doctor, the other a clergyman, came to me for electrical treatment for pain attributed to sciatica ; in each instance, on examination, the pain of the alleged sciatica proved to arise from an acute appendicitis.

Often the so-called sciatica is in reality sacro-iliac trouble, or disease of the hip- or knee-joint, or one of many other conditions.

True sciatica, or neuritis of the sciatic nerve, presents many points in common with brachial neuritis ; but in the former the affected area is more deeply situated, and consequently more inaccessible to physical therapy ; and it is moroever so surrounded by ligaments and other fibrous structures that the fibrositis accompanying the

complaint is usually more extensive and difficult to deal with.

The trans-vertebral diathermic application, which is so effective a method in brachial neuritis, cannot be imitated in this region by a corresponding application of the current concentrated upon the lower lumbar and the sacral vertebræ. A modification of the treatment consequently becomes necessary.

The method I usually adopt in the treatment of a case of neuritis of the sciatic nerve has already been outlined in the chapter on the continuous current. A large pad of several thicknesses of Turkish towelling, soaked in a 2 per cent. solution of common salt, is applied over the lower lumbar and the sacral vertebræ, also covering most of the buttock on the affected side ; this is then covered by a large tin or other electrode and attached to one pole, usually the negative, of the source of supply. The leg on the affected side is enveloped in a pad of similar material and similarly prepared, from the foot to the upper third of the leg, and a metal electrode is applied to the pad over the sole of the foot. At one time I applied a long metal electrode extending round the foot and nearly up to the upper limit of the lower pad ; but I abandoned this technique as I found that the greater part of the current travelled up the electrode, and concentrated at its upper limit, where it was liable to occasion electrolytic burns. Confining the electrode to the sole of the foot leads to more even diffusion of the current, and hence tends to prevent burns.

The treatment should be continued for at least forty minutes, and an attempt should be made to reach an intensity of 100 ma. I usually precede this treatment by five to ten minutes' application of the diathermic current, utilizing the same pads and electrodes ; about 0·5 ampere is sufficient to produce a comfortable feeling of warmth in the leg. This amount of diathermy should not be exceeded, its object being to raise the temperature at the

outset more quickly than it would be raised by galvanism, and only to raise it to such a point as can be maintained by galvanism. The treatment should be followed by massage, and if there is much stiffness by gentle movements.

By such a method it is usually found that a very large proportion of cases of sciatica, arising from simple causes, such as damp, cold, or exposure, are cured in about twelve treatments. The action of the treatment and the way in which these results are produced have already been dealt with in the chapter on the action of the constant current.

When we consider the morbid anatomy of sciatica, the duration of some of the cases before they come for electrical treatment, and the multiplicity of causes to which this form of neuritis is due, it is not surprising that we occasionally find cases which fail to respond to treatment.

In such cases a trial should certainly be made of radiotherapy. Many French writers advocate radicular radiotherapy as the standard treatment for sciatica; but I think that a method such as the one described above, both in view of the large percentage of cures that result from it, and because it is a stimulating and strengthening form of treatment, should be preferred to radiotherapy, the action of which is destructive; or, at any rate, the margin between its stimulating and destructive action is so indefinite as to be practically unascertainable: and at the same time one should bear in mind the inhibitory effects of the latter treatment on the function of adjacent organs, or even the possibility of some lesion to the organs themselves. The X-ray dosage usually applied is, however, a very small one, so that it is easy to over-estimate the latter point.

It is possible that where the complaint is of long standing, where there is advanced wasting with lack of tone in the muscles of the leg, with consequent loss of ankle reflex and with obliteration of the retro-malleolar fossæ, that time would occasionally be saved by commencing the treatment of the case by radiotherapy.

But even with such physical signs as those indicated, the treatment by intensive galvanism is so successful, and the results obtained are so lasting, that I prefer to give it a trial before proceeding to the application of radiotherapy.

In view of the irritation of the nerve roots or their trunk by the compression of exudate from the peri-neural inflammation, and the irritation due to pressure from the interstitial lymphoid elements between the nerve bundles, it is easy to understand how the decompressor action of diathermy or intensive galvanism, by dilating the blood-vessels in the surrounding areas, aided, perhaps, by the ' ionic massage ' alluded to in an earlier chapter, may relieve the pain and lead to a cure in the early stages of sciatica.

But when these exudates have in the old-standing cases become highly organized, and even the nerve fibres themselves are being destroyed and replaced by fibrous connective tissue, these forms of treatment are not sufficiently powerful, and recourse must be made to radiotherapy. For ' we can to-day assert that X-rays not only possess of themselves an analgesic action, but that this effect is the outcome of a decompression. The same thing happens in the case of cancer of the breast, and in its cutaneous metastases; the relief of pain that we observe in such cases, after an exposure to X-rays, can be attributed to a dissolution of the neoplastic lumps, and to a consequent freeing of the compressed nerve branches. This resolution action can be observed in cases other than neoplasms.

' The regression noticed in periadenitis, the increase in the amplitude of movement in certain cases of ordinary or bacillary chronic arthritis, are examples of the same kind. We see it also in certain cases of pachymeningitis ' (Babinski).

Radicular radiotherapy of the sciatica nerve appears to have been first practised by Freund, who in 1907 treated, by radiotherapy of the lumbo-sacral region, a patient suffering from cancer of the breast, who had

developed an acute sciatic pain, attributed to a supposed metastasis in the spine. Freund obtained a complete cure of the sciatica in this case, and attributed the result to a hyperæmic action of the X-rays analogous to that of heat, which increased the circulation, and so by causing a more rapid and active lavage of the tissues, more completely carried away the inflammatory products--an explanation which is not in accordance with modern views. Bergonié, Inbert, and others had already treated neuritis successfully in other parts of the body by radiotherapy. The treatment of radicular radiotherapy has been recently elaborated by Cottenot and Zimmern (3) ; it is to the latter of these that we owe the term ' radicular radiotherapy ', a term he introduced to specify the irradiation of that segment of the nerve which is included between its emergence from the cord and the plexus.

The technique of the French workers varies somewhat in the administration of this form of treatment : Zimmern adopts a penetration of about 8, 9, or 10 Benoist ; a filtration through 2 to 4 mm. of aluminium ; applied over the foramina of the fourth and fifth lumbar, and the first and second sacral vertebræ, the field of radiation also including the sacro-iliac articulation.

The dose administered is a small one, $\frac{1}{2}$ to 1 H (5 H = 1 Teinte B Sabouraud), repeated every two days, followed by a rest of eight to ten days after an accumulated dose of 3 H has been administered. Belot and others employ more massive dosage. Zimmern, assuming that sciatica is due to inflammatory products compressing the sciatic nerve, is of opinion that radiotherapy is capable of setting free the compressed nerve roots from the inflamed periosteum and cellular tissue that envelops them. He states that the analgesic action of radiotherapy can be nothing else than that of a decompressor acting on the origin of the nerves. Whilst a patient is under radiotherapy, Zimmern lays it down that all other forms of electrical treatment should be discontinued.

It is claimed that the majority of cases of sciatica are of radicular origin, and that radiotherapy of that region affords a speedy and reliable cure. I have found this treatment successful in two cases of sciatica that had resisted other forms of electrotherapy.

The Morton wave current is advocated by some writers as a very efficient agent in the treatment of sciatica. When the pain has disappeared, I have found this method of considerable service in the removal of any stiffness that may remain; but in the acute stages I have found it of little value.

As a constitutional aid to the treatment of sciatica, the diathermy or high-frequency condenser couch and the static charge have been recommended; the last named is the more likely to prove of value for this purpose. It should not be forgotten that exhaustion and a bad general state of health are predisposing causes to sciatica, and that the pain of the condition further exhausts the patient: a rest and change of air, after the pain has been relieved, are of great importance in completing the restoration to health and preventing a relapse.

Treated by the above methods, it will be found that the results obtained are most satisfactory, but it must not be thought that every case of sciatica can be cured by electrotherapy, or even by any other means. Old-standing cases accompanied by much fibrous thickening round the sacro-iliac and hip-joints will often obtain but little benefit, and even in recent cases, in rare instances, some deeply seated, peri-neural, or interstitial source of irritation may prove very resistant to treatment.

Reference to works on general medicine will show that sciatica is one of the very few conditions in which benefit may be hoped for from the application of electricity: but, when we read the method of application recommended by the authors, usually the application of one small electrode over the sciatic notch, the other, a small electrode moved indiscriminately over the thigh, a current

strength of from 2 to 5 milliamperes, applied for five or ten minutes, we cannot help thinking that these writers must be unduly optimistic of the results likely to follow from electricity applied in such an inadequate manner.

Trigeminal Neuritis (*Tic douloureux*). Neuritis, or as it is more commonly called, neuralgia of the fifth nerve and its anatomical connexions, excites such intense pain and suffering, and the operation for its relief is such a severe one, that its cure by electricity would be an immense boon for the sufferers from this terrible complaint.

The disease is generally believed to be situated in the Gasserian ganglion, and the cure which generally follows the removal of the ganglion indicates that it is often either so situated or peripherally located.

The best results in the electrical treatment of the complaint are obtained from intensive galvanism, or radiotherapy.

In the treatment by intensive galvanism, a thick pad, like half a mask, is cut to fit the affected side of the face, omitting the eyes, the nasal, and oral orifices. A continuous current of from 25 to 80 ma. is employed for half an hour with the patient in a recumbent position. Great care should be taken to increase and decrease the strength of the current very gradually. The best source of supply is from a battery of dry cells or accumulators, regulated by a shunt resistance.

Unless a strong current is employed, galvanism is often worse than useless: Soret (of Havre) records a case of very severe tic douloureux, which was temporarily improved by 56 ma., but in which no permanent cure was obtained until 80 ma. had been used. Of the four cases of severe tic douloureux that I have personally treated, the first was relieved of all her pain, and there had been no recurrence for five years when I last heard from the patient. The second case showed no improvement, either at the time of the treatment, or later. The third case showed very little improvement during the treatment, but has remained

free from pain, with the exception of a few rare and fleeting twinges, during the eighteen months that have elapsed since the galvanism was discontinued. The fourth case showed no improvement during the treatment, but since the completion of the course of twelve applications the severity and frequency of the attacks have much decreased.

A frequent feature in the treatment of this complaint, and, indeed, in the treatment of many complaints by intensive galvanism, is that the full benefit is not experienced until a short time after the course has been completed.

The French journals of electrotherapy contain many references to cases of tic douloureux successfully treated by radiotherapy. The technique adopted is in its main respects, except for the location of the radiation, identical with that employed in the treatment of sciatica.

Neuritis may be divided into many more subdivisions, but the method of treatment is the same, in principle, in them all. Care should be taken in each case to ascertain accurately the cause and the seat of the lesion, otherwise failure will often result. In herpes zoster, for instance, a disease of the posterior root ganglia of the spinal cord, the electrical treatment, diathermy is usually the most efficient form, should be applied over the spine at the level of the affected area, instead of, as is so often done, applying counter-irritation to the herpetic vesicles.

In coccygodynia, great relief and usually a permanent cure can be obtained from diathermy applied in the right manner. A cylindrical metal electrode should be inserted into the rectum and attached to one terminal of the apparatus : a pad and electrode the shape and size of the coccyx should be attached to the other terminal and applied externally over the coccyx. In this manner the heat is concentrated over the affected part and should be applied to the toleration of the patient for about ten or fifteen minutes daily.

Causalgia differs so essentially as regards its electrical

treatment from the usual forms of neuritis as to suggest an entirely different causation and pathology. Diathermy, which usually yields such marked relief in neuritis, aggravates the pain in causalgia. The condition results from wounds of nerves, and was fully described by Weir Mitchell about 1865. Wounds of the median nerve are by far the most common to be followed by causalgia.

The following is a typical case of severe causalgia which was under my care during the war. Wound of right forearm ; the pain, which was too severe to permit of the electrical reactions being taken, was of a paroxysmal character, the distribution was chiefly in the fingers of the right hand, it was excited by any sudden noise or disturbance, an aeroplane passing overhead brought on the pains to such an extent that the patient was unable to go into the hospital garden or on the balcony. As the result of the pain he was unable to smoke, he had very little sleep at night, and his appetite became very poor. The patient was very disinclined to move for fear of exciting a paroxysm, on walking he balanced himself on his toes with his knees bent, and although his right arm was in a sling, he further supported it by holding the fingers in his left hand. The skin on the hand was glossy and shiny, the nails long and incurved. The fingers were semi-flexed at the metacarpo-phalangeal, and fully extended at their phalangeal joints : they were closely and rigidly approximated, so as, it appeared, to give mutual support and splintage to one another.

From lack of food and sleep, and exhausted by the pain, he became thin and very careworn in appearance. Diathermy aggravated the pain without causing even the slightest temporary benefit. He obtained most relief by continually holding his hand under the cold-water tap in the bathroom, but the skin of his hand became so sodden from this procedure that the method had to be discontinued for fear of producing trophic sores. No form of drug, or other treatment, gave him any relief, until he was

given weak galvanic currents, rapidly interrupted by a Leduc interruptor. He obtained immediate relief lasting for some hours from this treatment, which was given for twenty minutes morning and evening. After its adoption he quickly became a changed man; his careworn expression passed away, he ate and slept well, and rapidly put on flesh. He ultimately made a good recovery so far as the pain was concerned. Other cases of causalgia reacted in a similar manner, but cases of pain from nerves compressed or constricted by band received more relief from diathermy. So marked, indeed, was this difference in the reaction to treatment that information of diagnostic value was thereby obtained.

I have suggested in an earlier chapter that the sudden and rapidly repeated stimuli, resulting from the use of the Leduc interruptor, may produce, by the recurrent hydrogen ion concentration they induce, a condition of exhaustion in the already irritated sensory nerves, somewhat analogous to the fatigue in a recovering peripheral nerve when over-stimulated by the faradic current. In the case of the motor nerve, loss of function results, as shown by the temporary absence of faradic excitability: so in the case of the already over-stimulated sensory nerve, a loss of function may result with temporary cessation of pain. Whatever the explanation may be, Leduc has shown by experiments on animals that, by means of these rapidly repeated stimuli of very low current intensity, it is possible to produce progressively a condition of anæsthesia, sleep, coma, convulsions, and finally the death of the animal.

Headache, Migraine, and Sleeplessness. Certain types of headache are very quickly relieved by the static charge combined with the head breeze. The type of headache, associated with low blood pressure, due to exhaustion or overwork, is the kind most suitable for this treatment. The patient reclines comfortably in the static chair for a period of thirty to sixty minutes, during which time

a negative charge is administered and attracts to the patient's head, by means of a suitable instrument, a positive charge from earth. In suitable cases the headache is entirely gone at the end of the treatment. The benefit resulting from this treatment is due to the rise in the blood pressure it causes, and consequently cases of high blood pressure should not be treated in this manner.

Very good results in the treatment of migraine often follow from the application of diathermy, and in the milder forms of 'facial neuralgia' relief can frequently be obtained from diathermic massage. Dr. Howard Humphris, whose experience of the method is greater than that of its introducer, writes as follows in his book, *Electrotherapeutics for Practitioners* (4), 'I have had striking success with diathermic massage of Turrell, i. e. with the patient on the autocondensation couch and connected up in the ordinary way, and a current of 500 milliamperes flowing through his circuit.'

Electrotherapy is by no means a panacea for sleeplessness, but there is a type of this condition in which the static bath and head breeze are most valuable applications. The cases of sleeplessness benefited in this way are similar to those cases of headache that derive benefit from a similar treatment, namely, cases due to exhaustion, worry, over-fatigue, and especially those cases of sleeplessness induced by the late and irregular hours entailed by too slavish a devotion to social pleasures and duties; cases also in which the patient is worn out with pain, is 'overwrought', or feels too tired to sleep. In such cases a short course of treatments from the static bath will often produce a complete cure.

Neurasthenia, where the blood pressure is low, 'pathological fatigue', is, as has already been pointed out in the chapter on the currents derived from the static machine, a condition which is usually benefited by the static charge and spinal breeze.

Hysteria. With the exception of recent cases of

hysterical aphonia and functional paralysis of the flaccid type, I do not advocate the application of electricity in cases of hysteria. In such a condition it is frequently applied as almost a punitive treatment ; this is exceedingly bad for the reputation of electrotherapy, and it is, moreover, as much calculated to harm as to benefit the patient.

In hysterical aphonia, however, of recent origin the success of faradic stimulation is generally very striking. A large indifferent electrode is placed on the back of the patient, or on any other convenient place, and a small active electrode is applied over the larynx, the patient is asked her name, she replies in a whisper, ' Mary Jones,' she is told that when the current is passing she will be able to speak more loudly. The active electrode is applied, and the primary of the coil is gradually sheathed, the muscles of the neck are thrown into contraction, and the patient exclaims ' Mary Jones ' more and more loudly, until normal phonation is attained. The patient leaves the hospital with a normal voice, and is assured that if a relapse occurs a repetition of the treatment will be attended with even more marked success. It is seldom that patients come for a second treatment, but occasionally they do so.

In the form of aphonia arising from shell shock, the above form of treatment, in my experience, invariably failed, and I quickly discontinued its use.

In the flaccid type of paralysis, as has already been pointed out, the excitation of contractions in the flaccid muscles by means of faradism quickly convinces the patients that their limbs are capable of movement, and usually voluntary power is quickly restored.

In the contractures arising from shell shock I invariably found that electricity was worse than useless.

In local anæsthesia, or paræsthesia of the skin, electrical stimulation affords an efficient means of exciting counter-irritation. It may be applied by a wire brush from the

finely wound secondary of the faradic coil, but is more effectively and conveniently administered by means of the disruptive static breeze.

In the occupational neuroses, such as writers' cramp, the one alleviative is rest, and neither electrotherapy nor any other therapy appears to exercise any direct influence on the complaint. Faradic stimulation and massage may be of service in some cases in tending to improve the secondary muscular wasting or stiffness which may result.

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CHAPTER IV

DISEASES OF THE CIRCULATORY AND RESPIRATORY SYSTEMS

The chief form of heart disease in which electricity is of service is that type in which the heart muscle is weakened by recent illness, or by inactivity, and in certain other types of fatty degeneration. In other words, the form of heart disease most suitable for electrical treatment is that which is likely to be benefited by graduated and suitably regulated exercise. Passive ergotherapy, as it has been termed, or generalized muscular exercise excited by the faradic current, both theoretically and practically, affords the ideal method in such cases.

The patient reclines in a comfortable chair composed of electrodes, and without any strain on his part, and with no expenditure of his nervous energy, each or all of the powerful muscles of the body are excited to contract with a force regulated by a resistance board, and to a range limited by superimposed sand bags. The speed at which the contractions take place, and their vigour, can be adjusted by the operator according to the requirements of the patient during the whole of the treatment with the greatest nicety and exactitude. The patient is continually under the direct observation of the operator, who can immediately moderate or stop the treatment on the slightest sign of exhaustion of the patient.

The effect of exercise in certain conditions of the heart has been frequently and favourably discussed in medical literature ; and there is no need to dilate further upon the subject beyond pointing out that where graduated muscular exercises are needed in heart cases it can most safely, most efficiently, and most readily be obtained by the Bergonié method of electrically provoked exercises.

The following is given as a type of case specially suitable for this treatment.

A patient consulted me with a view to 'ionic medication' for vague pains, flying about the body, believed to be of a rheumatic nature, and for general weakness. The history showed that about six months previously she had an attack of rheumatic fever, since which she had not regained her strength. She was very short of breath and was unable to walk more than a few yards. Her muscles were very weak and deficient in tone. The pulse was quick, there was no cardiac murmur, but the heart sounds were muffled and distant. The pains were of too fleeting a character to be suitable for electrical treatment, and the main indication for treatment was clearly the need for improved muscle tone and general strength. A course of twenty treatments of generalized faradism on the Bergonié chair was given, during which the improvement was steady and uninterrupted, and at the conclusion of the course the patient was able to walk a mile and a half. She was then instructed to continue her own treatment by steady and regulated walking exercise.

Diathermy through the heart would doubtless afford speedy relief to the pain of angina pectoris, but the bulk of the apparatus debars its general use in this disease.

Arterial Hypertension. In diseases of the heart and blood vessels, the use of electricity is most advocated in the treatment of high blood pressure. This is probably due more to the unsatisfactory nature of other remedies than to any special merit of electricity. For my part, I am unable to understand what more can be achieved by high-frequency currents, whether of tension or quantity, than can be obtained by the use of hot-water baths: but I admit that my teaching in this respect is at variance with that of most electrotherapists.

The temporary action of high-frequency currents of quantity in reducing blood pressure is very obvious; if

one heats the whole body by electricity, or by any other means, the blood vessels dilate and the blood pressure falls. But it is difficult to see wherein the special merit of electricity lies in this respect, for the same effect may be produced by other means, and the reduction, in whichever way it is produced, is of a very fleeting character. The effect of diathermy in lowering the blood pressure is, moreover, by no means a constant one ; for in certain cases of neurasthenia, attended with hypo-thermia, a rise of blood pressure is seen to result as the general condition of the patient improves, and I have seen a case of very high blood pressure in which the application of diathermy was followed by a further rise in the arterial tension.

Hyperarterial tension is usually associated with arterio-sclerosis : ' A high tension pulse may exist with very little arterio-sclerosis ; but, as a rule, when the condition has been persistent, the sclerosis and the high tension are found together ' (Osler).

A patient suffering from hypertension, after walking, or driving to the electrotherapist, has his blood pressure examined ; he then lies on a condenser couch for about twenty minutes, receiving about 2 amperes of current. The temperature of the whole body, as recorded by a thermometer in the mouth, rises for the first few minutes, reaching about 1° F. above the normal, and the pulse becomes accelerated ; then after about five minutes of treatment the blood vessels become dilated, the temperature and the pulse rate fall to normal, and continue so until the completion of the treatment. As the result of the heat, and perhaps to a small extent the rest also, the blood pressure is found to have fallen from about 8 to 10 mm. of Hg.

But this fall is temporary, unless very careful instructions, which alone would probably account for the small reduction that occasionally occurs, are given and scrupulously carried out in regard to the mode of life between the treatments.

In my own experience, I have not seen any case where the blood pressure was permanently reduced as the result of this treatment, and I do not think that the pathology of the condition or the physics of the treatment are such as would lead one to expect anything beyond a temporary improvement.

Arterial Hypo-tension. The low blood pressure associated with neurasthenia can generally be raised by a short course of treatment by the static charge and breeze in the manner already explained in the chapter on static electricity. Since, in addition to the immediate rise following this treatment, the stimulation of the afferent nerves of the skin leads to an increased activity of the suprarenal glands, it is reasonable to suppose that, as 'function makes structure', a certain degree of permanency should result from the treatment. The tonic effect of the static charge in cases where the general health has been impaired by overwork, fatigue, worry, or exhausting illness, is thus rationally and satisfactorily explained.

Diseases of the Respiratory System. Electricity has been but little used in the treatment of diseases of the respiratory system, but there undoubtedly exists a very wide field of usefulness for its employment in such cases. On *a priori* grounds there is every reason to believe that diathermy should exercise great benefit in such conditions as pneumonia, chronic bronchitis and emphysema, asthma, and pleurisy: and chronic empyemata should yield to the curative products of electrolysis in the same manner as other suppurative conditions, access to which is patent or obtainable by operative incision.

In pneumonia, so far as I am aware, this treatment has not been given a trial. Probably the difficulty of bringing the patient to the electrical department is one reason for this neglect, but there should be no insuperable difficulty in providing an apparatus in the wards of the hospital for the treatment of these and other conditions.

In private practice I have seen some benefit result from the application of diathermy in chronic bronchitis and emphysema ; but my experience of its use is insufficient to allow me to speak very definitely of the results obtainable. The pain of pleurisy can be readily relieved by diathermy.

I have tried diathermy in four cases of asthma, and in each instance obtained the satisfactory results that the nature of the disease and the action of the remedy would naturally lead one to expect. I am convinced that increased experience in the employment of diathermy in the treatment of asthma will confirm the high opinion that I have formed of it as a remedy in this disease.

The first case was a hospital patient with very advanced osteo-arthritis for which little relief could be afforded, but the severe asthma which was associated with it was very markedly relieved by diathermy.

The second case was that of a masseuse working in the hospital department, who suffered from asthma of a milder type ; she derived more benefit from diathermy than from any other remedy.

The third patient came to the hospital for treatment for rheumatoid arthritis, but she expressed doubt whether she would be able to attend regularly owing to her asthma, from which she got no relief except by constant use of Himrod's powder and a nebuliser. After diathermy administered through the thorax, she was able for the first time for many years to dispense with her former remedies.

The fourth case was that of a boy in the hospital who obtained unbroken sleep at night as the result of the first one or two treatments, and was shortly able to leave the hospital, and attend as an outpatient for treatment.

In the application of the treatment the main point of importance is to apply it slowly at moderate intensity for a period of not less than half an hour at each application. Using large pads, antero-posteriorly placed over the thorax, the current intensity should not be such as to

produce any sensation beyond that of comfortable warmth ; this usually amounts to about 1·5 to 2 amperes provided that the pads are large and are evenly applied.

The French appear to utilize the ozone and the nitrous oxide resulting from the electrical discharges of the high frequency apparatus as an inhalation for the cure of asthma. Nogier, in his book, *Électrothérapie* (1), gives a diagram of the apparatus, and summarizes as follows the results obtained by this method in the treatment of whooping cough: 'Although the ordinary duration of whooping cough is from two to three months, Bordier (2) and Vernay have shown that the fits of coughing can be entirely suppressed in two or three weeks by this treatment. Good results from the treatment have been systematically obtained in Paris hospitals for children.'

There appear, however, to be some grounds for suggesting that the action may be that of the nitric oxide and not of the ozone, for Bordier states that the best method of obtaining the ozone is by the *effluve* from the high-frequency apparatus, and that the static machine is 'un procédé illusoire de production d'ozone' ; now, according to Silvanus Thompson (*Electricity and Magnetism*), the spark and brush discharge produce nitric oxide, not ozone, but the silent discharge of the influence machine and that of the induction coil are particularly favourable to the production of ozone. The question has some importance, for there are reasons for believing that workers in an atmosphere in which ozone and nitric oxide are present in appreciable quantity, as in some large electrical works, and in a hospital department in which a powerful static machine is frequently in use, are more immune to the infection of influenza than the public generally. I noticed this in my hospital department during a severe epidemic of influenza in which the nurses in the wards were infected in large numbers, but none of the workers in the electrical department, where a powerful static machine was in constant use, were attacked ; until

one of them was taken away to relieve the pressure in the wards, when she alone of the electrical nurses fell a victim to the infection.

An interesting point in connexion with the rival claims for ozone and nitric oxide, as the therapeutic agent, is the fact that in certain districts it is the custom of the poor people to take their children suffering from whooping cough to the gas works to breathe the atmosphere there as a cure for the disease: also, during a recent severe epidemic, it was pointed out that the nitric oxide, for one finds but little ozone in the air at the gas works, at such places was useful in warding off attacks of influenza.

There is sufficient evidence to justify the trial of a powerful machine of the Ozonair type to produce gases, by means of electrical discharges, for the disinfection of lecture rooms, cinemas, etc., during an epidemic of influenza. The diffusive power of the electrically produced gases penetrates through the oral and nasal passages to the alveoli of the lungs, exercising a powerful disinfecting action throughout its whole path to a far more efficient extent than can be obtained from the less penetrating action of lotions, sprays, etc.

When the Simpson lamp for the production of ultra-violet radiation was first introduced, the inventor claimed great benefit in cases of lung disease from the inhalation of the fumes, given off from the fused wulframite; thereby he ingeniously diverted attention from the inconvenience caused by their smoky fumes; but when thoroughly tested at a London hospital no benefit was found to result from the inhalation.

References

1. Nogier, *Électrothérapie*, 1917.
2. Bordier, *Précis d'Électrothérapie*, 1902.

CHAPTER V

DISEASES OF THE DIGESTIVE SYSTEM, AND OF NUTRITION

The static charge by improving the general health is of service in some cases of chronic dyspepsia. Diathermy will relieve gastric pain, and its use has been recommended in gastric ulcer, but there is a definite risk of exciting hæmorrhage by its application in that condition ; so it should be administered with great care and only in carefully selected cases. The action of diathermy in relieving the malnutrition resulting from chronic dyspepsia is discussed later.

In disease of the digestive system, electricity is of most service in the treatment of the atonic forms of constipation.

In the acute form of atony, or paresis of the intestines, which occasionally follows abdominal operations, the faradic or sinusoidal currents, efficiently applied with suitable intensity, should theoretically be capable of exciting peristalsis, and of so remedying the condition : unfortunately the aid of the electrotherapist is not usually sought in these cases until the patient is moribund from toxæmia, or else the treatment is administered by some unqualified person, in a totally inadequate manner, from some small faradic battery.

Habitual constipation is due to such a multitude of causes and conditions that no one remedy is capable of meeting all the indications for treatment.

The most common cause, perhaps, is injudicious treatment at the commencement of the trouble ; when instead of trying to cultivate a regular habit of evacuation at a definite time of the day, or instead of treating the constipation by the correction of faults in the diet or

mode of life of the patient, recourse is made to purgative drugs, in doses of increasing strength, as the mucous membrane of the bowel becomes progressively more resistant.

Chronic constipation of a most obstinate type is frequently associated in a causal relationship with lax and flabby abdominal walls, due in the first place to the neglect of rational treatment at a confinement or other cause. Associated with this condition there is usually a lack of tone in the intestinal walls with consequent flatulent distension. The rational treatment of such a condition is the electrical method. Faradic stimulation should be administered in such a manner as to develop the muscles of the abdominal wall. It is useless to apply the current from a small coil by means of a small active electrode over each muscle, in turn, in a perfunctory manner. The treatment must be methodically and efficiently administered either by the Bristow method of graduated contractions, or, as I find much better in these cases, by means of the Bergonié chair. The back and seat of the chair form an indifferent electrode of one polarity, and the abdomen is covered with a pad and an electrode and is connected with the other pole. Treatment should be administered for at least twenty minutes daily, and it is with advantage followed by massage.

The muscles of the intestines can best be stimulated by means of the static induced current, a form of condenser discharge of high voltage. In this case the indifferent electrode is connected with the jar, which has a positively-charged outer coating; and a rectal electrode, preferably of the Benham Snow pattern, is connected with the outer coating of the other Leyden jar, which has a negative charge, and is inserted into the rectum. The current should be surged to the easy toleration of the patient by gradually opening and closing the discharging balls of the apparatus: or the author's automatic method of surging the currents derived from the static machine may be

employed. This method is a very simple one, and the necessary apparatus only costs a few pence. An insulated rod—a dry stick will suffice—is attached to the top of the case of the apparatus, so that it projects over one of the discharging balls, when in a position of wide separation. A thin copper wire is led from the other discharging rod A across the insulating stick B, and the thin copper wire drops vertically downwards, so that a weight attached to its lower end is in light contact with the discharging ball C.

While the weight D is in contact with the discharging

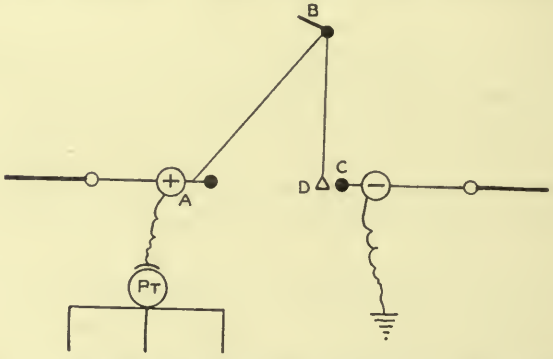

FIG. 25. Diagram to illustrate the author's method of surging the Morton wave current.

ball C, no current passes to the patient. On slightly moving the discharging ball C, or giving the weight a slight tap with an insulated rod or dry stick, the current will begin to pass to the patient, and will become stronger as the weight swings farther from the discharging ball, and weaker as it again approaches the ball in its return swing. The periodicity of the swing will depend on the length of the vertical wire, and the strength of the surge can be easily regulated from an almost inappreciable current to the patient's full toleration by the adjustment of the discharging ball C.

Mucous colitis is often benefited by a combined method of lavage and galvanism. The elaboration of the technique

of this method is due to Dr. Curtis Webb. He connects a large pad of Gamgee tissue, thoroughly moistened with a 2 per cent. solution of sodium bicarbonate, to the negative pole of the source of supply. The positive pole is formed by a wire spiral, covered by a rubber tube, perforated at its lower part, connected to a douche can containing about 2 pints of 2 per cent. solution of sulphate of zinc. This rectal tube is well oiled and introduced into the rectum. When about half a pint of the solution has distended the lower bowel, the constant current is gradually turned on until a maximum of 15 to 20 ma. is reached. The treatment is continued for 10 or 15 minutes, and during the whole of this time the solution of sulphate of zinc slowly flows. From this combined method of lavage and galvanism good results have been recorded. The main action would appear to be that of the nascent oxychloride of zinc formed by the electrolysis at the positive pole: such an action would certainly be calculated to be beneficial in certain diseased states of the mucous membrane of the lower bowel.

Pruritus ani. Milder forms of this condition can usually be cured by application of the ultra-violet radiation derived from the tungsten arc. The dose usually should be: current across arc, 15 amperes; duration, 5 minutes; distance, 12 inches; focused by a concave reflector; applied twice a week.

The more severe forms of this condition are best treated by radiotherapy.

Hæmorrhoids. Both internal and external hæmorrhoids can be successfully treated by diathermy. The internal variety suitable for this treatment is of two types. One type is chiefly characterized by pain, and is accompanied by little or no hæmorrhage: in the other type the hæmorrhage is the most pronounced sign, and the pain is usually slight or absent. The treatment of these internal hæmorrhoids is extremely simple, and is free from pain, the only discomfort experienced being due to the

introduction of the rectal electrode. The patient lies on his left side on a large indifferent electrode, or preferably on a condenser couch, connected to one terminal of the diathermy apparatus. A cylindrical metal electrode, attached to the other terminal of the apparatus, is well oiled and introduced into the rectum. A current of from 1·5 to 2 amperes is passed for ten minutes with the patient on his left side, he is then semi-rotated on the couch, without withdrawing the rectal electrode on to his right side, and a further period of treatment administered. A complete treatment of the lumen of the rectum is thus secured. Often one treatment is sufficient; in other cases it should be repeated daily, or on alternate days, for six treatments.

The results obtained are very satisfactory, and are attributable to the decompressor action of the heat on the neighbouring structures, thus relieving the tension, which causes the pain in the one case and the hæmorrhage in the other.

When the hæmorrhoids are in a more advanced stage and prolapse, a more severe treatment is required for their removal. The technique is as follows: The patient goes to the lavatory and forces down the piles as far as possible; he lies on a condenser couch, or on a large indifferent electrode attached to one terminal of the diathermy apparatus. The protruded piles are painted with a 5 per cent. solution of cocaine, or a hypodermic injection of 1 per cent. novocain is made round the anus. This part of the technique must not be hurried, and full time must be allowed for the cocaine to take effect: the novocain should not be injected into the base of the pile, owing to the oozing of blood which would then occur and by its high conductivity would prevent the necessary concentration of the current on the part treated. The operator holds an active electrode attached to the other terminal of the apparatus in his right hand by an insulated handle, and applies its small active surface to the pile to

be treated. The apparatus being previously adjusted to yield a current not exceeding 300 ma., contact is made by the operator by means of a foot switch. The current should be slowly applied, the more slowly, within limits, the less the pain, the firmer the coagulation, and the more permanent the cure. In a few seconds the hæmorrhoid will have turned an ashen-grey colour, or may even explode from the heated gases in the coagulated tissues. The current is then cut off by the foot switch and another pile treated. If the treatment is carried to the stage indicated by ashen-grey discoloration or explosion of the pile, a permanent cure will be obtained. The first patient I treated by this method, now more than eight years ago, has not had the slightest return of the trouble. The hæmorrhoids in this case had existed for seven years, causing great pain and discomfort, and occasionally profuse hæmorrhage, amounting, according to the patient's account, to the loss of a pint and a half of blood at a time. The patient experienced considerable pain as the immediate result of the operation, but not so severe as to prevent her from continuing her work, as a working housekeeper, without interruption.

A considerable amount of swelling of the surrounding tissues and some pain usually follow the operation; the patient should be kept quiet, but not necessarily in bed, for ten days. The amount of pain experienced varies very much, and it is very difficult to predict how severe it will be. Some cases, in which I have expected the pain to be severe, I have met out walking the next day. In other cases, where comparatively little tissue destruction has been occasioned, the pain has been so severe as to necessitate the insertion of morphia and belladonna suppositories. As a rule the pain is not great if the swollen parts can be fully returned and retained within the rectum. Hot fomentations to the perinæum afford the necessary relief in the majority of cases. In only one case in my experience has there been any appreciable

disturbance of the general health or a rise of temperature. This disturbance occurred in a patient liable to frequent attacks of malaria; the temperature rose on the night of the day upon which the operation was performed, and rose subsequently after each evacuation of the bowels for ten days, the temperature reaching as high as 103° F.

I have endeavoured to minimize the pain of the operation by stopping the treatment as soon as the patient said she felt the pile, upon which cocaine had previously been painted, become really hot under the electrode. But I found that cases treated only to that extent were very often not permanent. It is too subjective a method to be successful. The painlessness of the operation depends upon the care with which the cocaine is applied, and upon the slow and gradual application of the treatment. In the case of small isolated piles, especially if they are pedunculated, the pain should be slight; but large masses of piles cannot be destroyed by diathermy, or by any other means, without considerable pain and discomfort resulting from the treatment.

The advantages of the method are obvious: no preparation of the patient is necessary, no nursing home is required, no general anæsthetic is needed, no confinement to bed is entailed, and the results are usually permanent. In about ten days the coagulated mass separates, leaving a healthy and granulating surface, from which a few drops of blood may ooze as the destroyed mass falls off. There is no danger of either primary or secondary hæmorrhage, the deeper vessels are firmly plugged, and the superficial ones are themselves coagulated.

The Diseases of Nutrition

Obesity. The inventive genius of the eminent electrotherapist, Professor Bergonié, of Bordeaux, has provided us with an electrical method, based on rational and physiological principles, for the effective treatment of obesity.

Bergonié (1) describes his method as the application to the whole muscular mass of the body of an electrical excitant, specially chosen for provoking, passively and painlessly, rhythmical contractions in this mass of muscles, thereby increasing the energy expended by the physiological work and by the heat which it sets free.

The patient, when undergoing this treatment, reclines in a specially designed chair, the back and seat of which take the form of four large electrodes.

Other large electrodes are applied to the abdomen, forearms, and thighs.

These electrodes, eleven or twelve in number, covering nearly the whole skin surface of the body, are connected with eleven or twelve separate rheostats, which control the supply to each individual part, and are in turn governed by a central rheostat, which controls the supply to the body as a whole.

In very fat persons the total surface covered by electrodes is as much as 10,000 square centimetres. With such a large surface exposed, the density of the current employed is exceedingly low, amounting only to about 1/100 of a milliampere per square centimetre.

The details of the instrument have been evolved with the greatest exactitude and nicety by the inventor. For the source of supply, all the usual methods were carefully investigated; and, as the outcome of much experiment, the faradic current was finally selected. The interruptor of the coil was found to be a very important factor in obtaining painless contractions, and after long and minute researches, a trembler, giving 50 interruptions a second, emitting a musical note, always of a high and equal pitch, without pauses or variations, was obtained. The faradic coil employed is the most powerful utilized in medical electricity; it yields a current from its secondary of about 500 ma. at from 12 to 20 volts. The power absorbed in the primary, with a main supply of 110 volts, is about 60 watts (24 volts and 2·5 amperes).

In order to interrupt the secondary current, and to give the patient the necessary periods of repose, the reversing metronome has been selected as the most efficient form of instrument. It is arranged so as to give 120 beats a minute, and its double interruption, with a suitable setting of the platinum contacts which dip into mercury-containing cups, yields a double oscillation divided into four periods. 'During the first quarter of a second the muscles are at rest; they contract, excited by one of the poles, during the second quarter; they rest during the third; contract afresh, excited by the other pole, during the final quarter.'

The selection of the brisk interruption of the metronome, in preference to the more gradual interruption by a surger, is a particularly happy one, and is in full accord with physiological principles. The sudden, brisk, quick interruption by metronome induces a form of muscular contraction, which is the counterpart of the exercises of speed (adopting Lagrange's classification of different types of muscular exercise): the slow gradual contraction, excited by the surger, is the electrical counterpart of the physiological exercises of strength.

The electrodes are kept in place during the treatment by the super-position of bags of sand. These bags serve the triple purpose of securing even co-aptation of surface, of affording an easily regulated means of increasing the work performed, and also of restraining any jerky movement of the limbs. The total weight of sand applied in this way sometimes exceeds 220 lb.

The amount of current, measured by a hot wire amperemeter, varies with the patient: a muscular patient may only require about 25 or 30 ma., whilst a really fat and œdematous patient may need as much as 70 or 80 ma. to excite efficient contraction. In no case should the current be so strong as to excite painful contractions.

The duration of the seances should be gradually

increased from 20 minutes at the first application up to an hour, or even an hour and a half, when the patient has become thoroughly accustomed to the treatment. Bergonié advocates in some cases the administration of two treatments a day.

The treatments should be given about five times a week, and the course should usually consist of at least twenty treatments.

Sometimes an astonishingly rapid decrease in weight is obtained; but, personally, I am content with a reduction averaging a pound a treatment, and this amount I usually succeed in obtaining. Of course the general build of the patient, the *dimensions énergétiques* of Bouchard (2), must be taken into consideration.

There are many ladies with whom a certain plumpness is a normal and a not unattractive condition; who, nevertheless, wish to be reduced to a slimness in accordance with the inexorable claims of fashion, which is not their normal or physiological state. To attempt such a reduction by this method is to court failure; for the method is essentially a natural or physiological one, and it is not possible by its means to reduce the weight to an abnormal extent.

As a rule in a really obese patient, a reduction of about 10 per cent. of the weight should be secured. Since, when all has been said and written, the maintenance of a normal weight, that is to say, the preservation of the mean, relative to the individual, between stoutness and thinness, depends on the maintenance of the correct balance between intake and output: therefore, while we increase the output by ergotherapy, we must take care not correspondingly to increase the intake, or there will be no weight reduction. It is, therefore, necessary to limit the amount of the diet, and the more this is reduced in reason the more rapid will be the reduction in weight. It is a rather remarkable feature of the treatment that patients, who had previously failed to exist with comfort under

a strictly regulated Banting diet, find but little discomfort or difficulty in considerably reducing the amount of their food whilst they are undergoing passive ergotherapy.

Bergonié has quaintly remarked that the patients to a great extent live on their own tissues, and only need a little salad to complete the dietary.

As regards the lasting effect of the treatment, this in the main depends upon the patient herself. A patient, after years of inactivity and over-eating, may have become so obese that to instruct her to take a 5 or 10-mile walk daily is an obvious absurdity. But such a patient, having lost 10 per cent. of her body weight, and her muscles having been more than proportionately developed, is placed in a position, by carefully regulated exercise, to maintain the reduction, and the accompanying improvement in the general health : and, if she relapses for want of attention to this simple precaution, the lapse is attributable to her own fault rather than to that of the treatment.

An improvement in the general condition of the patient is usually noticeable after about the third treatment ; the first thing that attracts the patient's attention is a sense of general fitness, analogous to the feeling of a well-trained athlete after a carefully regulated course of training. A feeling of lightness, or of buoyancy, as the patient sometimes describes it.

The first objective sign is usually a reduction in girth : before the scales record any marked reduction of weight, hooks and eyes in the region of the waist may need readjustment. A pathetic tale was once related to me of a lady, over 22 stone in weight, who underwent this treatment in London. She had not been able to move from her couch for several years, and so stout and flabby had she become that a nurse was engaged to move the pendulous abdomen from side to side every two hours, to prevent the occurrence of eczema intertrigo. Now this lady, after her first few treatments, actually went up in

weight : but she was by no means discouraged on that account, because she had already gone down in girth.

I cannot vouch for the correctness of this story, but I quote it to illustrate a rather important point : that very fat and flabby patients may at the outset have a slight and temporary increase in weight, due to the increase in the muscular development, for it is not until the muscles are developed that they can be utilized to burn up the fats by their vigorous contractions.

One of the many advantages of passive ergotherapy by the method of Bergonié is that all the large muscles of the body are exercised simultaneously to an extent that can be regulated as a whole, or which can be readily adjusted to the requirements of each part or muscle. For example, if the abdomen is too pendulous, or too coated with fat, the treatment can be in such a case concentrated on the abdomen, the fat burnt up, and the muscles developed and improved in tone.

' Firm and vigorous abdominal muscles form the best girdle against obesity.' (Lagrange). No single athletic exercise can be regulated with the same nicety, or adjusted with the same exactitude. Let me illustrate this point from Dr. Lagrange's book, *The Physiology of Bodily Exercise* (3), published in 1889, long before the method of passive ergotherapy was thought of. ' When we see fat men take to fencing in order to get thin, we notice that in them the internal fat is far from being the first to disappear ; the abdomen is the region which retains with most tenacity its supply of fat. There can be nothing more awkward than the shape of a body of a man in this ungrateful period when the fat has disappeared from his arms, his chest, and his legs, while his belly remains as large as ever. The regions which have been made to work in fencing have lost their fat ; the arms and legs appear slender, and the chest, which has been freed by the work of the pectoral muscles, appears shrunken by comparison with the abdomen, which has remained of its

original size. It is only by continuing his exercise for some weeks still that the fat man is able to gain what he above all desires, the diminution in the size of his belly.'

Another great advantage of the Bergonié method is that it is automatic, in the sense that its operation is in no way dependent on the cerebral control of the patient. The patient is thus, as regards the exercise, placed in the position of the already skilled and trained athelete, who by constant practice has acquired an automatism of action, which, by diminishing the necessary concentration and expenditure of nervous energy, enables him to perform his exercises with far less fatigue than an unskilled and untrained person. Passive ergotherapy thus fulfils the indications which we deduce from Lagrange's law: 'The muscular work being equal, the sensation of fatigue is the more intense, the more active the intervention of the cerebral faculties demanded by the exercise.'

If any doubt remains as to the great superiority of passive ergotherapy over all other methods for the treatment of obesity, contrast the healthy, vigorous, and athletic appearance of the patients who have undergone this treatment with the shrivelled-up look presented by the victims of a starvation diet, with their pinched countenances, their parchment skins, and their shrunken and lustreless eyes. Or compare them again with a patient who has undergone a course of drug or glandular therapy, which often owes what little efficiency it possesses to the conversion of a fat optimist into a dyspeptic pessimist.

The Electrical Treatment of other conditions arising from Defective or Faulty Nutrition.

The electrical treatment of these conditions we owe also to the pioneer work of Professor Bergonié. He adopts two methods of treatment, passive ergotherapy

and ' La Diathermie Ration d'Appoint (4) '. He sums up the action of the former by stating that passive ergotherapy should be regarded not as a form of treatment for any special disease, but rather as a therapeutic syndrome, capable of being associated with suitable drug therapy or other forms of treatment. He expresses the opinion that the treatment of such diseases as gout, chronic rheumatism, of certain cases of diabetes, of lithiasis, both biliary and hepatic, of enlarged liver, and many other conditions, should necessarily include passive ergotherapy to render their treatment rational, efficacious, and lasting.

At first sight it naturally appears irrational to apply the same remedy for the reduction of the weight of a fat person, and for increasing the weight of a wasted person suffering from malnutrition. I have already quoted several times from Dr. Fernand Lagrange's excellent work on *The Physiology of Bodily Exercise*, a book, which, though published more than thirty years ago, and to a large extent lost sight of amid a multitude of recent publications of a similar kind, still remains one of the best works of reference on the subject with which it deals, and has the special merit for my purpose, that having been written so long prior to the introduction of the methods with which we are dealing, it is free from the taunt of excessive or biased enthusiasm in relation to these forms of treatment.

Dr. Lagrange, in the following passage, shows that this double rôle of ergotherapy of increasing or decreasing the weight is in no way inconsistent with the physiology of muscular exercise. ' We have seen that work has two opposite influences on nutrition : it increases the gains, and it also increases the losses of the system. The hygiene of work essentially consists in balancing these two opposed results ; but certain conditions of exercise may make now one, now the other, predominate, and it is possible to obtain almost at will, by the aid of muscular work either

an increase or a diminution in the weight of the body.'

The argument in support of the *diathermie ration d'appoint*, or the supplementary ration of diathermy, is that in a number of marasmic conditions there is an inability to take or assimilate the nourishment necessary both for the maintenance of the heat and the nourishment of the tissues of the body: and that to overfeed such cases only makes matters worse, for the weakened digestive system rebels against the overfeeding, and indigestion is then added to the pre-existing troubles. On the other hand, by transfusing heat through the tissues by means of diathermy, that portion of the food which would be otherwise burnt up in the maintenance of the body temperature is diverted to the nourishment of the body, and so helps to establish the normal equilibrium between intake and output. 'It is a fortunate occurrence,' remarks Professor Bergonié, 'by no means a rare one in physiotherapy, that the more grave the condition is, the more efficacious the remedy becomes (4).'

The method of application of this treatment is by means of large electrodes covering in all a superficial area of from 1,000 to 3,000 square centimetres. They are applied in the following manner: one on each side of each upper arm, one on the inner and outer side of each thigh, and one on the inner and outer side of each leg, 12 electrodes in all. They are secured in position by rubber bandages. The electrodes on one side of the body are connected with one terminal of a diathermy apparatus, those on the other side with the other terminal. An intensity of current of from 1 to 2·3 amperes is administered for about 40 minutes. With these large electrodes and this intensity of current, the current density only amounts to about 1 ma. per square centimetre, and is consequently so far within the limit of safety that the intensity of the current may be safely increased, if it is desired to do so.

In the case of a typical application quoted by Bergonié,

the following formula represents the intensity of current applied :

$$\frac{2{\cdot}3 \text{ amperes}}{1200 \text{ cm.}} = 0{\cdot}00191 \text{ ampere.}$$

To obtain satisfactory results from this treatment, and also from ergotherapy, whether applied for obesity or malnutrition, it is essential that its administration should be under the constant observation and direct control of a medical man. The indications for variations in the degree, in the location, in the character of the treatment, so frequently arise, that it is impossible to issue general instructions to a nurse or masseuse which will meet all the requirements of the case during the course of treatment.

The general indication for the supplementary diathermy ration occurs whenever it is desirable to raise the temperature of the body as a whole. In fact, this form of treatment is nothing more than the application to the body as a whole, and to general and constitutional diseases, of that form of treatment which electrotherapists have found so beneficial in the treatment of local diseases and lesions.

Bergonié points out as special indications : the marasmic diseases of children ; athrepsia induced by neoplasms ; malnutrition associated with stricture of the œsophagus or cancer of the stomach or liver ; the hypothermia following profuse hæmorrhage.

The most noticeable physical results recorded by Bergonié as the result of experiments are a rise of the temperature in the axilla of 2·1° C. in 16 minutes with a current intensity of 1·7 ampere, whilst the rectal temperature was only raised 0·1° C. The blood pressure was raised from 15 to 19 cm. of mercury. A definite lowering of the respiratory exchanges occurred :

Respiration during ten minutes.

Before diathermy.	After diathermy.
2·95 litres oxygen consumed	2·14 litres
2·62 litres of CO_2 output	1·96 litres

Bergonié concludes that we have in diathermy the most rational and active means of assisting the organism, when in a state of physiological misery, whatever may be the cause of this condition ; for we are able to bring to it, in the natural form of heat, a supplementary ration which compensates for its deficient energy, without making any call upon the digestive system.

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CHAPTER VI

THE GENITO-URINARY SYSTEM

In the Male

Incontinence of urine. If, after obvious causes, such as phimosis, calculus, etc., have been removed, and suitable methods of training and discipline have been given a sufficient trial, the trouble still persists, electrical treatment of this troublesome condition offers sufficient prospect of improving or curing the condition to warrant its adoption.

In children, the usual method is to apply the faradic current from a coil with a coarsely wound secondary. One pad is placed over the lumbar region and the other on the perinæum. The treatment is given daily for about ten minutes of a strength permitted by the toleration of the patient.

In the treatment of the incontinence of urine in adults, I have obtained the best results from the use of the unidirectional discharges of high voltage obtained from the so-called Morton Induced Currents of the static machine.

A rectal electrode is introduced and connected with the Leyden jar, the outer coating of which is negatively charged; a pad is secured just above the pubes, or to the perinæum, and is connected with the outer coating of the other jar, which has a positive charge. The discharging balls of the static machine are gently opened and closed, or the author's automatic static surger is employed, so as to give a surging character to the current. Each treatment has a duration of about fifteen minutes. The explanation of the action of this treatment naturally depends on the view we take of the pathology of the condition.

If the trouble is due to an atony of the sphincter of the bladder, then the beneficial effects of the treatment would be attributed to its action in the strengthening of the sphincter. If, as is more generally held to be the case, it is due to faulty cerebral control, the improvement resulting from the treatment would be regarded as the outcome of a reflex stimulation and a strengthening of such control.

Urethral calculi. The primary action of the diathermy current in developing heat in any organ however deeply situated, and the secondary effect of this heat in inducing relaxation of spasm, suggests the employment of diathermy to relieve renal colic, and also by relaxing the spasm, set up by the presence of the calculus, to facilitate its passage through the ureter.

As the result of an error of diagnosis, I on one occasion applied diathermy for a dull aching pain in the back, occasioned by a calculus gripped in the ureter. Considering the pain to be due to lumbago, I applied diathermy transversely through the back; the pain was at once relieved, but on returning home the patient was about twenty minutes later seized with the agonizing pain of renal colic, and in due course passed a stone.

Gonorrhœa. Electrical treatment may be applied with success to the early or later stages of this disease ; but those who have had much experience of general practice will know that the majority of these cases can be more simply cured by urethral injections, such as mercurol, aided by suitable medicines. Occasionally, however, old-standing and intractable cases arise, which are not so easily dealt with ; and these can usually be cured by an electrical method first described by Bouchet, in the *Journal des Praticiens*, February 9, 1907 (1).

Tousey, in his book, *Medical Electricity*, thus describes Bouchet's method : ' A soft rubber catheter with multiple eyelets is used to irrigate the urethra with some solution, such as 1–2 per cent. solution of sulphate of zinc, which

forms the positive electrode for a current of from 1 to 10 ma. Bouchet makes the electric connexion with the liquid by the use of a fine platinum wire, which passes through almost the entire length of the catheter, and which is fastened to a metal tube inserted between the tube from the irrigator bag and the catheter. It is to this metal tube that the positive wire is secured. The other electrode is applied to any other indifferent region. An irrigation with two quarts of solution is enough for each application. In acute cases, where the treatment is begun on the first or second day of the disease, Bouchet has found that daily treatments cause immediate disappearance of the discharge and sterilize the urethra of gonococci in fourteen days. In thirty chronic cases he obtained a complete cure in three or four weeks by applications made every other day.'

The therapeutic action here is, of course, identical with that which occurs in the electrolytic treatment of septic sinuses, endometritis, mucous colitis, etc., and is clearly due to the stimulating or caustic action, varying with the nature of the solution employed and the strength of the current, of the nascent products of the electrolysis on the neighbouring tissues.

Neuritis of the testicle is relieved by diathermy. Nagelschmidt has devised a form of suspender electrode for applying the current, for which a glass or porcelain bowl, filled with salt solution, in which an electrode is placed, forms quite an efficient substitute. A large indifferent electrode is applied to the spine, and a diathermy current is passed of a strength easily tolerated by the patient.

Impotence. Of the treatment of this condition by electricity I have no experience. Nogier (2) sums up the results obtained as follows: 'In certain cases the cure is fairly rapid, in others it requires as many as twenty-five or thirty treatments to obtain the desired result.' I should imagine that for a very large number of

cases even thirty or sixty treatments would be insufficient.

Ulcerations on the penis, such as soft chancres, usually yield readily to the ultra-violet radiation.

Diseases of the Prostate. The Morton wave current has been much extolled as a remedy for enlargement of the prostate. In no condition is an accurate diagnosis of greater importance, or more difficult to obtain, before the commencement of treatment than in enlargement of the prostate. It is perfectly obvious that the Morton wave current is entirely unsuited for malignant disease, and yet the exclusion from the diagnosis of malignancy in prostatic enlargement often baffles the most skilled urologists. The Morton wave current cannot benefit a calcareous or even a fibrous prostate beyond assisting to massage away a co-existent or secondary œdema, which may be aggravating the condition. An œdematous or congested prostate, on the other hand, or a prostate in whose acini chronic suppuration is proceeding, may be immensely benefited by the Morton wave current. I have had many failures in the treatment of enlarged prostates owing to this difficulty of ascertaining the primary cause of the enlargement.

The action of the Morton wave current on the prostate is wholly and solely one of massage ; it is, however, not only the most effective form of prostatic massage, but it is the only really effective form.

As the result of the patient's electrical discharge through his prostate, the whole gland vigorously contracts, and so squeezes out any œdema or other fluid accumulation. The periods of contraction alternate with periods of rest.

Owing to the high voltage employed, the whole gland is permeated with the current and contracts as a whole when the discharge takes place. These vigorous contractions, so excited, alternating with periods of rest 120 times a minute, exercise a type of auto-muscular massage,

compared with which the ordinary forms of prostatic massage are most inefficient and ineffective.

The application of the treatment is painless, it is the cleanest and the least objectionable form of prostatic massage. The patient is given a rectal electrode, with an olivary metal terminal projecting at right angles from an insulating vulcanite base, the patient himself usually introduces the electrode, keeps it in place by sitting on the insulated stem, through which runs a wire connected with the positive pole of the static machine. The rods of the apparatus are separated to an extent well within the toleration of the patient, and the treatment is thus administered for about fifteen minutes.

Occasionally we meet with cases of prostate obstruction which yield most readily to this treatment. Such a case was the following: a clergyman, of about sixty years of age, was sent to me for electrical treatment of an enlarged prostate, which occasioned such frequent micturition that he was unable to preach or to lecture. A short course of the Morton wave current completely cured this patient, and he has remained free from any trouble of the kind for six or seven years.

In cases of old-standing gonorrhœa, it is often necessary thoroughly to drain the crypts, follicles, or acini of the prostate from accumulations which may be the residual cause of the trouble. For such conditions the Morton wave current is the ideal treatment.

Painful and inflammatory conditions of the prostate can usually be relieved or cured by diathermy, applied by means of a metal electrode in the rectum and an abdominal pad. The current should only be sufficient to produce a feeling of warmth. Adhesions within or around the prostate may be broken down by the Morton wave current.

In the Female

Endometritis. In no disease is the value of electrical treatment more clearly demonstrated than in endo-

metritis. It was from the success which I obtained, when in general practice, from the electrical treatment of endometritis, that I was first convinced of the very great value of electricity as a curative agent. I then found that cases of endometritis with suppurative discharge, which had undergone months and years of irrigation without benefit, were usually cured by one to three treatments of intra-uterine electrolysis. In two instances married women, who had been sterile for five or more years in consequence of a purulent discharge, and who became pregnant after their endometritis had been cured by electrolysis, reproached me for not warning them that as the result of the electrical treatment they would again become capable of conception.

The electrical treatment of endometritis is so simple, so safe, so successful, and so painless that its general adoption in place of curetting can only be accounted for on the ground that it is so little known.

Contrast the nature of this treatment with that of curetting.

In electrolysis no previous preparation of the patient is needed, a zinc or copper electrode is introduced within the uterine cavity with no more pain or discomfort than attends the introduction of a uterine sound for diagnostic purposes, the strength of the electrical current is immediately reduced if it causes any pain; after about fifteen minutes' treatment the patient is able to walk or drive home—no nursing home is required. The action of the electrolytic products automatically extends and permeates to every part of the lining of the uterus, to every crypt and follicle of the mucous membrane. The electrolytic products have an antiseptic action, and their cauterizing effect is readily controlled by the duration of the treatment and the intensity of the current, and the latter cannot be excessive if it is not pushed beyond the easy toleration of the patient.

Curetting, on the other hand, usually necessitates the

inconvenience and expense of a stay in a nursing home, it entails the risks inseparable from the administration of an anæsthetic, the possibility of subsequent trouble resulting from the forcible dilatation of the os uteri, the operation is of necessity blindly and perfunctorily performed, a raw surface is laid open for septic invasion, and there is no guarantee that the most diseased portion of the mucous membrane has been reached by the curette. In cases where there are placental remains to be removed, curetting is the more effective operation ; but in uncomplicated cases the good results from electrolysis are far more certain and constant than those from curetting. Examination of the curetted portion of the mucous membrane is often of value ; but electrolysis often affords equally valuable information of another kind. For, if with the electrical method acute pain on one or other side of the uterus accompanies the application of a current of moderate strength, it may be safely concluded that the tubes or ovaries on that side are affected ; in such cases the electrical treatment should immediately be discontinued, and the case should be sent to a surgeon.

The technique of the treatment is important. The patient's abdomen is enveloped in bath towelling soaked in salt solution, and the metal electrode should extend completely round this pad, so as to ensure an even distribution of the current within the uterus ; this pad is connected with the negative pole of the source of supply. A zinc or copper uterine sound is attached by a rheophore to the positive pole of the battery, and is carefully introduced within the uterus. In cases where there is a septic discharge, it is customary to recommend the choice of a zinc active electrode, on account of the special antiseptic properties attributed to the action of the oxychloride of zinc ; where hæmorrhage is a prominent symptom, the copper electrode should be chosen, on account of the styptic properties of the copper salts. The vaginal or extra-uterine portion of the electrode

should be insulated by means of a piece of rubber tubing or a portion of an unused gum-elastic catheter. Where there is ulceration of the os uteri, as is commonly the case where the disease is of old standing, this condition may be treated simultaneously with the interior of the uterus, by wrapping a pledget of wool or lint, soaked in 2 per cent. solution of sulphate of zinc, round the stem of the electrode, and pushing it against the os uteri by means of the insulating vaginal tube. The patient is placed in the Marion Sims position, and, the electrodes being in position, a galvanic current is very gradually applied up to an intensity of 20 to 30 ma. for a period of fifteen to twenty minutes.

The strength of the current should be immediately reduced if it occasions pain. Occasionally towards the end of the treatment some discomfort may arise from the excitation of uterine contractions; if it persists after the completion of the treatment, it may be readily removed by diathermy or the application of the leucodescent lamp. The risks of the treatment would appear to be merely those of the introduction of a uterine sound.

Dysmenorrhœa, Menorrhagia, and Amenorrhœa. My attention was first directed to the very valuable relief obtainable from diathermy in cases of painful menstruation, by a patient whom I had been treating for abdominal pain, assumed to be due to a floating kidney, saying to me, 'Do you know that since my last treatment I had the first menstrual period, free from pain, that I have had for 17 years?' Acting on this accidental hint, I found that five out of six cases of severe menstrual pain derived very great benefit from diathermy; a result that a realization of the action of diathermy and the spasmodic nature of menstrual pain would naturally lead one to expect. The treatment is applied by a large indifferent electrode over the back, and an active electrode over each ovarian region in turn. The pads should be about 20×10 cm. in size, and the current should be

approximately two amperes for ten minutes over each area. The treatment is given daily for the three days preceding an expected period, and is usually discontinued during the period ; but if the pain recurs, the treatment should be administered during the period. The effect of the treatment is occasionally to bring on the period before the expected time.

Menorrhagia, occurring about the time of the menopause, is best treated by radiotherapy. Menorrhagia occurring in young married women can, after the possibility of pregnancy has been with certainty excluded, be satisfactorily treated by intra-uterine electrolysis by means of a copper electrode.

Amenorrhœa, for which no obvious cause can be found, can frequently be remedied by diathermy. The treatment is applied in very much the same manner as for dysmenorrhœa ; but the current should be of lower intensity, and applied for at least half an hour. It should be applied for about six days before the period is calculated to be due. Menstruation has been regularly established in the few cases which I have treated in this manner. The action of the treatment is clearly due to the increased functional activity of the ovaries, resulting from the increased blood supply induced by the administration of the heating current.

Some ' neuralgic ' pains in the ovarian region, and also some pains attributable to peritoneal adhesions, can be relieved by diathermy.

Sterility. The treatment of this condition obviously depends upon its cause. If the sterility is regarded as in any way due to spasmodic dysmenorrhœa, a condition commonly associated with sterility, then a trial should certainly be made of diathermy applied to the ovarian region. Where sterility is due to a diseased condition of the endometrium, no method holds out better prospects of success than the electrolytic treatment of endometritis. In an earlier chapter a case of recurrent abortion is

recorded, in which a full-term child was born in due course after treatment by electrolysis, after frequent curetting and various other measures had been previously tried without success.

Uterine Fibroids. These are best treated by the radiation of the ovaries and uterus with X-rays.

One of the most exhaustive and instructive paperson the radiotherapy of uterine fibroids is that by Dr. Béclère (3), entitled 'La Radiothérapie des Fibromyomes utérins, Résultats, Mode d'Action et Indications d'après une Statistique de 400 Observations personnelles', communicated to the Brussels Congress of the 'Association des Gynécologues et Obstétriciens de Langue française', September 27, 1919.

In the method advocated by Dr. Béclère the treatments were of moderate strength and were administered weekly. The penetration was of the value of a spark gap 15 to 20 cm. Filtration, 5 mm. aluminium. Distance, tube 18 to 22 cm. from surface radiated. Duration, each radiation 5 minutes. An application to each ovarian region at each seance. Intensity, 2 ma. through tube. Pastille measurement, after traversing filter, 3 to $3\frac{1}{2}$ H.

Of the 400 cases upon which Dr. Béclère's observations were based, 24·5 per cent. of the patients were 50 years of age or more; 64 per cent. were from 40 to 49; 11·5 per cent. were from 30 to 39.

15·5 per cent. of the tumours were within the limits of the pelvis. 84·5 per cent. extended into the abdominal cavity.

The following were the number of treatments required:

4	to 11	treatments	in	38	patients.
12	,, 14	,,	,,	202	,,
15	,, 20	,,	,,	109	,,
21	,, 30	,,	,,	45	,,
31	,, 50	,,	,,	6	,,

The most noticeable results obtained were the suppres-

sion of the periods and the diminution in the size of the tumours. In four cases only of the 400 was surgical interference called for—it was in those cases required on account of the profuseness of the hæmorrhage. With his more recent and perfected technique, Dr. Béclère thinks that even this small number might be reduced.

The periods ceased as in the following table :

Without any reappearance of the periods in			3 patients.
After one appearance		61	,,
,, 2 appearances		128	,,
,, 3 ,,		89	,,
,, 4 ,,		29	,,
,, 5 ,,		9	,,
,, 6 ,,		8	,,
,, 7 ,,		3	,,
,, 8 ,,		4	,,
,, 10 ,,		2	,,

The diminution in the size of the tumours is shown in the following table :

From 1 to 2 centimetres in	12	patients
,, 3 ,, 4 ,,	42	,,
,, 5 ,, 6 ,,	73	,,
,, 7 ,, 8 ,,	62	,,
,, 9 ,, 10 ,,	52	,,
,, 11 ,, 12 ,,	26	,,
,, 13 ,, 14 ,,	10	,,
,, 16 ,,	1	patient

Dr. Béclère concludes that, with the exception of those cases that imperatively call for surgical interference, all types of uterine fibromata are suitable for radiotherapy.

In view of the work of Regaud, which so clearly proves that certain cells, and especially cells of such functional activity as characterizes the cells of the ovaries, vary greatly in respect of their radio-sensibility[1]

[1] It will materially assist the comprehension of the phenomenon of radio-sensibility if it is clearly realized that the expression 'the selective action of X-rays', so often applied, is a very incorrect and misleading one : the so-called selective action is

at different stages of their existence, it would be a very strong argument in favour of the divided doses of Béclère's method, if this period of maximum radio-sensibility was reached by different ovarian cells at different times. The work of Wintz, however, tends to show that this is not the case, but that the period of maximum radio-sensibility of the ovarian cells occurs simultaneously in the different ovarian cells during the first fortnight following the menstrual period.

It is of interest to contrast the method of Béclère, which may be regarded as representing the best technique for the divided dose method, with the application of a single sterilization dose advocated by Dr. Wintz of Erlangen.

In the method of Dr. Wintz, a mean depth from the skin, after compression has been applied, is assumed for the surface depth of the ovaries. A calculation is made by very precise technique of the amount of radiation which the ovaries will receive at this assumed depth.

Assigning a value of 100 to the skin erythema dose, the dose necessary for the sterilization of the ovaries is stated to be 34 (34 per cent.).

Very heavy filtration by 0·5 mm. of zinc is employed. The ' self-hardening water boiling tube ' (for convenience, termed the ' Wintz tube ') is previously calibrated by means of a standard tube, and by aid of tests with the iontoquantimeter ; the only measurement of the dose employed in the actual working in the treatment room is one of time.

For the correct administration of this time measurement, Wintz points out that the following factors are essential :

The dose produced by the X-ray tube per unit of time must be known.

not an attribute of the X-rays, but is the result of the varying sensibility of the cells at different periods of their cycle to X-rays or the gamma rays of radium.

The penetrating power of the rays necessary for the treatment must be known.

Tubes must be employed whose dose per unit of time remains constant, and also the penetrating power of the rays produced must remain constant. (Other conditions remaining the same.)

X-ray apparatus must be employed of which the output is constant.

Measuring instruments of the required accuracy must be used to show the current passing through the tube, and also the E.M.F. which is applied to the terminals of the tube.

Using a port of entry 6×8 cm. the erythema dose is obtained, under certain conditions of tube and current, in the following times at the various focal-skin distances :

At 23 centimetres focal-skin distance in 35 minutes.
At 30 „ „ „ „ 59 „
At 50 „ „ „ „ 165 „

Wintz strongly advocates the administration of a sterilization dose at a single treatment, lasting for 2 to 2½ hours, applied within a fortnight of a menstrual period. After such a treatment he states that a recurrence of hæmorrhage will be prevented. But if the irradiation is administered in the fortnight preceding the occurrence of the menstrual period, one or more hæmorrhages may occur. This observation is of great importance as indicating the period of maximum sensibility of the ovaries.

If a 'complete sterilization dose' has already been administered, it is not safe to repeat it in the event of recurrence of the periods.

If a complete sterilization dose is given at one treatment in the first fortnight following a menstrual period, no further hæmorrhage occurs in 95 per cent. of cases. If the dose is divided into several sittings, hæmorrhage completely ceases in 93 per cent. If the dose is given in

one treatment in the second fortnight after the period, one further hæmorrhage occurs in 80 per cent.; and if the treatment is given at a corresponding time, and in divided doses, two further periods will occur in 84·4 per cent.

Wintz, though he is so strong an advocate of the single dose, admits that in nervous patients its administration is impossible, and in such cases he recommends its division into two applications.

This method of sterilization is not usually applied in cases of simple menorrhagia before the age of 40 has been reached; its chief sphere lies in the hæmorrhage preceding the menopause.

Wintz regards the presence of a sarcoma as no contra-indication to the treatment; on the contrary, he states that in such cases the results of irradiation are far superior to those of surgical operation.

In the last $3\frac{1}{2}$ years Wintz claims to have carried out 500 sterilizations without a single failure. The same sterilization dose is administered for both young and old patients.

'In 7,000 cases which we have treated, there are only two in which at a later date, sometime after the irradiation, damage to the skin occurred.'

A comparison of the divided dose, as recommended by Béclère in 1919, with the single dose method, advocated by Wintz in 1920, shows how rapidly radiotherapy is developing, and the direction in which it is advancing.

It is too early at present to speak with dogmatism of the superiority of either of the rival methods, but it would appear that the single dose is the more certain and the more speedy cure, and that the risks attending its administration are no greater than those of the divided dose method. The lengthy exposure of $2\frac{1}{2}$ hours may, however, lead many, both operators and patients, to prefer the less drastic method of the divided dose with its lessened liability to induce constitutional disturbance;

and the good results obtained by this method over a relatively lengthy period of time must not be overlooked.

Time alone will show which method will survive, but the probability appears to be that a modified technique, on the lines of the single dose, will be the method of the future.[1]

Though radiotherapy for cancer is by no means confined to the treatment of this disease when occurring in women, nevertheless it has been hitherto employed in this class of the disease to such a preponderating extent that this chapter affords the most convenient opportunity for discussing its action.

Up to the present time it must be frankly confessed that radiotherapy has not yielded very encouraging results in the treatment of cancer. The work of Dr. Wintz and his school, however, sheds so much fresh light upon this subject that his illuminating book should be read by all those specially interested in the treatment of cancer.

Wintz finds that the necessary dose to destroy cancer cells is 110 per cent.; their radio-sensibility therefore is not greater than that of the skin. The difficulty of treating epidermal cancer is thus obvious, for it is of course impossible to treat it through more than one port of entry. The upper layer of cancer cells may be destroyed, but the underlying cells will receive an insufficient or even a stimulating dose. Wintz, however, points out that, if the cancer growth is situated about 3 cm. from

[1] Béclère, in an appreciative criticism of the work of Seitz and Wintz, concludes that the divided dose method of moderate intensity is still to be preferred to the single dose intensive method: because the former does not produce any constitutional disturbance calculated to interfere in any way with the patient's mode of life or with her occupation, the result is obtained with a minimum of radiation, and it is the only method suitable for large tumours. Béclère, however, proposes in the future to employ a more penetrating radiation than he has hitherto used.—Béclère, 'Sur la rœntgenthérapie des fibro-myomes utérins', *Journal de Radiologie et d'Electrologie*, October, 1921.

the surface they can be successfully treated by employing a focal distance of 100 cm.

Where there is general metastasis, the cumulative action of the X-rays needed to destroy the individual deposits is greater than the body (the white corpuscles) can tolerate, therefore such cases cannot be successfully treated by radiotherapy.

In the treatment of uterine cancer, Wintz employs six ports of entry, necessitating a duration of treatment from 4 to 4½ hours. Morphia is hypodermically administered so that the patient may sleep through the greater part of irradiation. The after-effects vary considerably; some patients vomit during the treatment and this vomiting may continue the next day.

Sometimes diarrhœa occurs, and the patient may not recover from these and other after-effects for from eight to fourteen days.

Wintz emphasizes the importance of not spreading the dose over several sittings. A few patients do not recover from the action of the irradiation on the blood, and die in about the same time that they would have done if the growth had remained untreated. Wintz gives a latitude of 20 per cent. between which the success or failure of the treatment depends. There is a danger of severely injuring the intestines if too large a dose is given —it should consequently under no circumstances exceed 130 per cent.

Wintz expresses the opinion that, in future, uterine carcinomata should be irradiated, and not operated upon.

The tendency of the Wintz method of the radiotherapy of cancer appears to be towards replacing surgical interference by primary radiotherapy in certain non-disseminated cases of cancer.

The Wintz method, therefore, does little or nothing to realize the hopes which many have entertained that in radiotherapy we might find a cure for disseminated and inoperable cases of cancer. The only hope of achieving

a result, so much to be desired, would seem to lie, not in the use of more powerful apparatus, the limit of which appears to have been reached in the Wintz instrumentation, but in the discovery of some method by which the radio-sensibility of the cancer cells can be increased.

The advance in radiotherapy, resulting from the work of Drs. Seitz and Wintz (4), does not rest solely on the attainment of a more intensive method of radiation; but it is largely due to the more exact technique of these investigators, which enables the worker more readily and more accurately to ascertain the dosage of radiation which is actually received by the tissues irradiated.

Pruritus vulvæ. The electrical treatment of this condition is identical with that of pruritus ani which has already been described. Some cases of this distressing complaint will resist all treatment.

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CHAPTER VII

DISEASES OF THE BLOOD, AND THE GLANDS

The action of the radiation from X-ray tubes and from radium upon the blood is of very great importance, both on account of its beneficial or therapeutic action in leukæmia, and its malignant or morbid action on the workers constantly exposed to the radiation.

A most instructive and exhaustive paper on the action of X-rays on the blood, entitled ' De l'Action des Rayons X dans la Leucémie ', by MM. A. David et R. Desplats (1), appeared in the *Archives d'Électricité Médicale*, May 25, 1912. This paper not only expounds very fully and clearly the ideas of the authors, but also fairly and critically examines the views propounded by other writers, and concludes with a bibliography of the subject, including 37 references. It should be read in its entirety by all those specially interested in this subject. The following comments and extracts will give an idea of the scope of the thesis.

David and Desplats commence by quoting the various theories which have been propounded to explain the action of X-rays on the blood.

1. *The microbic action of X-rays.* Senn (2) attempted to explain the action of X-rays in leukæmia by their destructive action on hypothetical microbes, which at one time were thought to be the cause of the disease. The microbic origin of the disease is now practically abandoned, and the amount of radiation employed in this treatment would probably be insufficient to account for their destruction if they were present in the blood.

2. *The action of the X-rays on the hæmatopoietic organs.* Heinecke (3) has demonstrated the great radio-sensibility of lymphatic tissue : but though the tissue may appear

to be completely disorganized by the radiation, nevertheless, in 8 to 14 days, complete regeneration of the follicles may have occurred.

This marked radio-sensibility belongs to the lymphoid tissue ; the pulp of the spleen and the bone marrow is not by any means so radio-sensitive.

David and Desplats arrive at the conclusion that 'though the destruction of the lymphocytes may be explained by the destruction of the lymphoid tissue, the destruction of the myelocytes may not admit of an analogous interpretation'.

3. *The action of the X-rays on the blood in circulation.* Aubertin and Beaujard (4) were the first to study contemporaneously the effect of radiation on the blood in circulation, and on the hæmatopoietic organs. This they accomplished by administering doses of therapeutic strength to the whole bodies of small animals.

The first thing noticed was a leucocytosis due to an increase of the polynuclears. This phase was of such a fleeting character that, unless the blood was carefully and systematically examined soon after the irradiation, it escaped notice. It might even disappear as early as three hours after the exposure. A similar fleeting occurrence of polynuclear leucocytosis can be noticed in cases of myeloid leukæmia soon after the irradiation of the bone marrow.

This leucocytosis occurs too soon after an irradiation to allow of the formation of fresh leucocytes. It is probably an exodus of polynuclears from the bone marrow, where they are kept in reserve pending a sudden call for their services, in the same way that a fire engine is held in reserve for emergencies at a fire station (Ehrlich).

In the same way Aubertin and Beaujard regard this as an emigration under the influence of the X-rays of the polynuclears from the myelogenic organs ; and they believe it to be an emigration which is not peculiar to the polynuclears of the myelogenic organs, but that it is one

which will be found in the lymphocytes from the lymphogenic organs.

Post-mortem examinations of guinea-pigs, killed two to four hours after exposure, demonstrated that the spleen did not present any signs of injury; and that the marrow of the bones was in full activity, macroscopically more red, and microscopically more congested, with fewer polynuclears.

The leucocytosis was succeeded in the irradiated guinea-pigs in about 24 to 36 hours by a marked leucopenia; at that time, however, there was a percentage predominance of polynuclears, in spite of an actual diminution in their count. This is attributed to the greater vulnerability of the mononuclear elements to the X-rays, and also in part to the specimens having been prepared from dried blood. The phase of immigration is thus succeeded by one of destruction in the case of the irradiated guinea-pig, and similar evidence of destruction is found in cases of leukæmia after they have been exposed to X-rays.

As regards the red corpuscles a slight but constant diminution in their number followed the irradiation of the guinea-pigs.

Aubertin and Beaujard point out that the leucopenia cannot be due to a hypo-functioning of the lymphoid tissue, because the lesions to the lymphoid tissue are fully restored after 48 hours. It cannot be due to medullary insufficiency, because it occurs in spite of a marked medullary hyper-activity, which is more marked as the leucocytic count is below the primitive count.

They conclude that this leucopenia, in the conditions under which they have observed it, results from a direct or indirect destruction (by the intermediary action of leucolysins) of the leucocytes in the whole organism, and this can occur without medullary degeneration, for in spite of marked medullary hyper-plasia the destruction exceeds the formation.

David and Desplats conclude from these experiments of Aubertin and Beaujard that leucopenia, in the conditions in which it is observed after radiotherapy, cannot be attributed to a destruction of the lymphoid or myeloid tissue.

4. *The leucolysins.* The leucolysin theory explains the therapeutic action of X-rays in leukæmia by the formation, as the result of the radiation, of substances in the blood capable of destroying the white corpuscles.

Helber and Linser (5) held that the action of X-rays was due to a destruction of the lymphocytes circulating in the blood, and that the changes in the hæmatopoietic organs were due to the action of leucotoxins thus set free.

Various substances, such as a biochemical modification of lecithin (Werner (6)), have been suggested as capable of formation in this way, and capable of effecting the results stated.

Curshmann and Gaupp (7) went farther, and produced experimental evidence in support of the theory. ' Struck by the fall in the number of leucocytes provoked by an irradiation in a case of lymphatic leukæmia, they injected under the skin and into the veins of rabbits the serum of leukæmic patients who had undergone irradiation. They found that a considerable diminution in the number of the white corpuscles occurred, the minimum being reached in $4\frac{1}{2}$ hours after the injection. If the leukæmic serum was rendered inactive by heating to 60° C. for half an hour, the leucocytic fall is scarcely shown, and is, moreover, at its lowest an hour and a half after the injection. Curshmann and Gaupp do not hesitate to attribute a leucolytic force to the leukæmic serum, due to a leucotoxin, the action of which is shown by a marked leucolysis four hours after the injection. This leucotoxic ferment only exists in the serum of irradiated leukæmics.'

An objection was raised by Capps and Smith (8) that it did not necessarily follow, because the irradiated leukæmic serum was leucotoxic to the white corpuscles of the rabbit, that it was therefore leucotoxic to the human

white corpuscles, and especially to those of leukæmic patients.

In reply to this objection the following experiment by Curshmann and Gaupp may be quoted: The serum from a leukæmic patient, who had been treated by radiotherapy at regular intervals for two years, was injected on repeated occasions, during a period of three months, under the skin of another patient who had previously received no treatment of any kind. Each injection was followed by a destruction of the leucocytes very similar to that following radiotherapy. It was found that the leucocytes returned to their normal number more rapidly after each injection. Thirteen days elapsed after the first injection before a return to normal occurred, nine days after the second, and six days after the third. This is important, as it is in accordance with the generally acknowledged fact that radiotherapy in cases of leukæmia becomes progressively less effective after repeated treatments.

Ambrozio injected the serum from an irradiated rabbit into a normal rabbit, and also into a rabbit with hyperleucocytosis—leucolytic action supervened in each case, affecting chiefly the mononuclear cells, and especially the lymphocytes—and he found that the exposure to X-rays of the non-irradiated animal did not confer on the serum any leucolytic action. Ambrozio further experimented as follows: A dose of 4 H, very hard X-rays, was daily administered for 10 successive days to the spleen and bones of a healthy young man. At the end of ten days a preparation of his blood was made, and 10 c.c. were injected daily into a patient with acute leukæmia. In 24 hours a leucolysis appeared, very definite and very rapid, if the injection was made intravenously; slower and more lasting if the injection was made subcutaneously. Accompanying the leucocytosis there was an improvement in the white count, also an increased excretion of uric acid; the spleen diminished in size.

David and Desplats, as the result of their very careful and extensive research, formed the opinion that the direct destruction of the hæmatopoietic tissue did not explain the action of radiotherapy in leukæmia : on the contrary, the changes in the hæmatopoietic organs were secondary to a destruction (direct or indirect) of the white corpuscles circulating in the blood. They give the following reasons :

(1) *The destruction of the hæmatopoietic tissue theory* (the theory of Heinecke). The therapeutic doses employed are insufficient to provoke a degeneration of the myeloid or lymphoid tissues. Post-mortem examination of animals after irradiation with doses corresponding to those of therapy shows no marked degeneration changes in the hæmatopoietic organs.

'The experiments and arguments of Aubertin and Beaujard appear to us to give amply sufficient reason for the rejection of the primitive theory of Reinecke, and we content ourselves with remarking that clinical experience is, in this instance, in full accord with experiment ; the leucopenia excited by a series of radiations does not actually start always immediately after a séance, as it would if the action corresponded to a rapid destruction of the constructing tissue ; we have on the contrary several times seen it start 8 or 10 days after the X-ray seances, by which time the degenerative lesions have had ample time to repair themselves. On the other hand, this leucopenia is not produced with abrupt suddenness, but it increases progressively for a certain number of days, intersected, perhaps, it is true, by some bursts of leucocytosis.'

(2) *The theory of the destruction of the white corpuscles circulating in the blood.* If the deeply situated organs do not receive a destructive dose, neither can the white corpuscles during the short time of their circulation, although it may be recurrent, through the field of irradiation, receive a sufficient dose to destroy them.[1] 'Can we

[1] This would surely depend upon the radio-sensibility of the

imagine that a direct destruction of white corpuscles could be retarded for a period of three weeks or a month before it should show itself ? Is it possible on such an hypothesis as this to explain why some séances of X-rays are followed by a considerable leucopenia, whilst other séances do not influence the composition of the blood at all ?

'Finally, can we comprehend why in certain patients, as we have seen to be the case, in spite of repeated radiotherapy, the number of the white corpuscles progressively increases ? '

(3) *The theory of leucolysins.* David and Desplats think that it is impossible at the present time to deny the existence of leucotoxins, or to deny the influence of X-rays on their appearance, or to invalidate their manifest action in diminishing the number of the white corpuscles. They raise, however, one objection to their being regarded as the curative agent in the radiotherapy of leukæmia, and this they regard as a very serious one to the acceptance of such a theory, namely, that the white corpuscles of certain patients are not reduced in number, and in some cases may even increase in number after the application of X-rays. Such cases appear to be very exceptional; David and Desplats have recorded one or two cases, and others have been recorded by Œttinger, Fiessinger, and Sauphar (9), and also by Provinciali.

David and Desplats sum up their very valuable treatise by the following conclusion :

1. The stimulating action of X-rays in small doses should be considered apart from their destructive action in large doses.

leucocytes or the radio-sensibility of their nuclei, and the length of time that some of them were in the radiation field : both of these are unknown factors, but the radio-sensibility of the leucocytes is clearly very high, as is shown by the readiness with which they are destroyed in comparison with the red corpuscles, and some of the white corpuscles must be in the radiation field for an appreciable time.

2. The destructive action of X-rays does not seem to have any relationship with a large number of the hæmatological and anatomical-pathological phenomena observed in the evolution of leukæmia treated by X-rays.

3. These phenomena are much more rationally explained by the stimulating action of X-rays.

4. The spleen and other hæmatopoietic organs are simultaneously stimulated in all their deficient functions, particularly in their leuco-destructive function, and in their hæmatopoietic functions, proportionately, on the one hand, to the dose of X-rays, and on the other hand, to the functional quality of the tissues excited.

5. This conception is not opposed to the existence of leucolysins circulating in the blood, but one may consider the leucolysins as the products of the secretion of the different macrophages in the blood, which vary with the dose and are proportional to the richness of the hæmatopoietic organs in macrophages.

They consider that it is definitely a vital reaction, by means of which the hæmatopoietic organ, affected by the leukæmic process, responds to the therapeutic stimulus; and this reaction leads by different mechanism to return towards the normal hæmoleucolytic formula, which has been so profoundly disturbed.

David and Desplats's arguments in favour of a double mechanism, the one constructive, the other destructive, simultaneously functioning, do not appear to offer either a probable or a satisfactory explanation of the therapeutic action of radiotherapy in leukæmia. A far more probable explanation appears to be that some leucocytes are destroyed: namely, those which happen to be exposed in the field of radiation whilst their nuclei are in a sufficiently radio-sensitive stage, and that as the result of the destruction of these leucocytes or their nuclei a leuco-toxin or ferment is produced, which exercises a destructive action on the white corpuscles in the blood, and possibly may induce changes in the spleen and other

glands. The two objections which David and Desplats raise to such an hypothesis are far from insuperable. First, as regards the very rare cases in which no leucolysis or even a leucocytosis follows the radiation : it is surely by no means unusual to find exceptional cases which fail to react to treatment whatever the nature of the treatment may be, or are even made worse by a treatment which benefits the majority of patients : such idiosyncrasies are explicable on a variety of grounds.

The other objection, that leucolysis does not occur for 8 or 10 days after the treatment, is more in favour of than opposed to the theory of the formation of a toxin resulting from the destruction of a certain number of leucocytes. Such a delayed occurrence is analogous to the skin reaction following a full pastille dose of X-rays, and the liberation of a toxin resulting from the destruction of the nuclei may explain the delayed occurrence in each case.

The strong point in favour of such a theory is the very definite and distinct evidence that such a toxin is formed as the result of exposure to X-rays. It is far easier to conceive such toxins as resulting from the destruction of the leucocytes or their nuclei by X-rays than to regard them as produced by the secretion of macrophages circulating in the blood in variable quantities.

It is interesting to find in the progressive rapidity with which the leucocytes return to their normal numbers after successive injections of serum from irradiated patients, a condition analogous to and to some extent explanatory of the progressively decreasing efficiency of therapeutic radiation when applied to a patient in successive courses. It appears to suggest the formation of an antitoxin.

It is very important from the point of view of therapeutical technique to arrive at a definite conclusion, as to whether the X-rays act on the spleen or on the circulating white corpuscles : it is, perhaps, best in the present state of our knowledge to continue the custom of irradiating

the spleen, for, in any case, a large quantity of blood circulates through the field of radiation in that area, and it is not impossible that the white corpuscles may undergo some change in that organ which may render them specially radio-sensitive. On the other hand, the unfortunate occurrence of leucopenia in X-ray and radium workers strongly suggests a form of radiation, prolonged, of low intensity, and administered to the body as a whole.

Hodgkin's Disease. The enlarged glands of this complaint yield readily to radiotherapy of moderate intensity. The permanency of the results is very uncertain.

Exophthalmic goitre. If, as appears to be incontestable, the radiation of hard X-rays, or the gamma rays of radium, has a restraining influence on glandular secretion, and if 'the arguments in favour of the hyper-secretion theory of this disease appear to almost all observers to be of overwhelming strength' (Rendle Short), then both radio- and radium-therapy may be described as exercising a specific action in this disease.

So far as my personal experience and observation extend, it appears to be that the success of this treatment depends, as is so commonly the case in other diseases, upon its early adoption.

If drug therapy and other forms of treatment are persisted in, in spite of their inefficiency, until the disease has reached an advanced stage, then radiotherapy will frequently fail. But if radiotherapy is adopted in the early stages of the complaint, both the symptoms and the physical signs will quickly disappear. As regards the permanency of the results obtained in such conditions as this, the exciting cause of which is not fully understood, it is very difficult to speak with both correctness and dogmatism.

The technique of the radiotherapy of Graves's disease differs in no essential respect from that already described in the treatment of the ovaries in cases of uterine fibroids.

Since the thyroid gland in this disease reaches its state

of maximum enlargement about the time of the menstruation, this would appear to be its period of greatest radio-sensibility, and consequently indicates the special need for treatment during such activity.

Tuberculous and other glands. Enlarged and diseased glands react to radiation from X-rays or the gamma rays of radium in proportion to their metabolic activity, in accordance with the theory of Regaud.

The most quickly and readily affected glands are those which are enlarged as the result of simple inflammatory changes. Lympho-adenomatous glands are the next in order of radio-sensibility : and then in sequence follow the sarcomatous, tuberculous, and carcinomatous glands.

Tuberculous glands, though coming third on this list, are often capable of being very successfully treated by X-rays. A most exhaustive paper on this subject, ' Le Traitement radiothérapique des Adénites chroniques bacillaires ', was communicated by Dr. Max Roques (10) to the Congrès de l'Association Française pour l'Avancement des Sciences, held at Nîmes, August, 1912.

The following are some of the conclusions at which Dr. Max Roques arrived : That the X-rays have no direct action on the bacilli. That they exercise an indisputable action on the diseased tissue cells. That they exert a destructive action on the leucocytes, on the lymphoid cells, and on the diseased elements generally. That they appear to excite proliferation of the connective tissue cells. That radiotherapy clearly exercises a favourable influence on those forms of chronic adenitis which are regarded as due to tubercle bacilli, and that this favourable action is shown by the marked diminution of the swelling which almost invariably occurs, and frequently even by its complete disappearance ; by the drying up of the suppuration ; by the rapid cicatrization of the ulcers and fistulæ ; by the removal of the keloids ; and by an æsthetic result better than can be obtained by free incision and drainage. He considers that the treat-

ment is contra-indicated when there is a condition of hypo-thermia, when the disease is too advanced, and where the infection is generalized. He advocates the employment of radiotherapy for intra-thoracic glandular involvement which is occasioning pressure symptoms, and in abdominal involvement where operative treatment is contra-indicated, and in which the general condition of the patient is not too seriously affected. He regards the treatment as exercising a very favourable influence on the general health of the patient.

Cancerous glands. The efficiency of the present methods of radiotherapy is insufficient to justify its adoption in the case of glands which can be removed by operation: but it is, nevertheless, of considerable value in the treatment of inoperable cases. The most marked effect of radiotherapy in these cases is the relief of pain. This result, which is alone sufficient to justify the adoption of the treatment, is probably due to the action of the radiation on the inflamed connective tissue cells rather than to a direct action on the cancer cells.

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Quoted by David and Desplats.

CHAPTER VIII

DISEASES OF THE SKIN

Diseases of the skin are in many instances quickly and readily cured by electrical methods, even after the customary remedies have been applied for long periods without success.

It is the chronic and atrophic form of skin diseases rather than the acute and inflammatory that yield most readily to electrotherapy. The chronic conditions, such as alopecia areata, psoriasis, chronic eczema, in which the blood supply and nutrition of the skin are at fault, are specially amenable to the stimulating influence of powerful ultra-violet radiation or small doses of X-rays. Electrotherapy, in such cases, strikes directly at the cause of the trouble by causing a superficial hyperæmia which speedily restores the efficient nutrition of the skin.

In alopecia areata, for instance, the smooth, shiny, anæmic, atrophic appearance of the skin is in a short time after the application of powerful ultra-violet radiation replaced by skin of normal appearance ; and if the hair follicles have not completely atrophied, a new growth of hair quickly appears. It is difficult to make too high claims for ultra-violet radiation in the treatment of this condition, and it may with accuracy be stated that if a re-growth of hair is possible, it can be obtained more quickly, with greater certainty, and with less inconvenience to the patient, by means of ultra-violet radiation than by any other means (Figs. 26, 27). There is one essential to this treatment, that is, the radiation employed must have the necessary energy ; some of the instruments sold for this treatment are of such diminutive power that they cannot provide the necessary output. In order to obtain the best results, the energy should not be less

than that yielded by a current of 15 amperes across the arc. The application should be made at a distance not greater than 12 inches from the arc for at least five minutes, and must result in a marked hyperæmic reaction. Chronic eczema often yields readily to ultra-violet radiation; if this treatment fails, as it will sometimes do in old-standing cases, weak doses of X-rays, about one-third of a pastille, should be employed. The previous application of ultra-violet radiation materially assists the action of the X-rays, enabling a similar effect to be produced with a smaller radiation. The action of the X-rays in the small doses employed in the treatment of eczema is a stimulating one. The X-rays may, if it is preferred, be administered through a thin aluminium filter; but in that case their action is still due to the soft rays, namely, the residual soft rays that pass through the filter. That a minimum of soft X-rays actually passes through the thickest filtration is shown by the skin reaction that occurs after radiation by the Wintz method, in which a filtration of 12 mm. of aluminium is employed with an exposure for thirty-five minutes.

Pustular eczema, or impetigo in the milder and more recent forms, speedily yields to ultra-violet radiation; for the success of the treatment, however, it is absolutely essential that all crusts should be removed. In cases of long duration, or where there exists difficulty in the complete removal of the crusts, a preliminary course of treatment with zinc electrolysis should be given, using a weak galvanic current, and an active positive electrode of zinc applied over the ulceration through a pad soaked in a 2 per cent. solution of sulphate or chloride of zinc. When the affected parts have been thoroughly cleaned in this manner, ultra-violet radiation is the most speedy method of completing the cure. The static breeze should never be applied to the skin when it is in a pustular state; for this powerful current has the effect of scattering the germs and infecting the neighbouring areas of the skin.

FIG. 26. Case of alopecia areata before treatment.

FIG. 27. The same patient after three months' treatment by ultra-violet radiation from the tungsten arc.

Tinea cruris. The fungus of this condition appears to be on or sufficiently near the surface of the skin to be reached by the ultra-violet radiation, and, if proper precautions are taken to prevent reinfection from the clothing, a cure may often be brought about by a single treatment from the tungsten arc. Usually, however, difficulty will be experienced in accomplishing the necessary disinfection of the clothes, and in such cases white precipitate ointment should be rubbed on the treated parts to prevent their reinfection between the radiations.

Ringworm of the face can often be cured by ultra-violet radiation ; but the more deeply seated ringworm of the scalp will need the more penetrating X-rays for its destruction. The treatment of ringworm of the scalp has almost developed into a speciality of its own, and it appears to be passing from the control of the medical profession into the hands of lay operators. The general adoption of X-rays for the treatment of ringworm appears to be due more to the definite period which can be fixed by its employment for a cure, and hence for the return of the patient to school, than to any real therapeutic necessity. In a fairly extensive experience of this trouble among school children of the dispensary class, I cannot recollect having had any special difficulty in curing ringworm by the simple method of applying Ung. Hydrarg. Ammon., making sure that the ointment was rubbed in night and morning, the old ointment being thoroughly removed before the fresh was applied. The routine application of X-rays in these cases is taking a very large hammer to crush a very small nut, and it is certainly a procedure that is attended with appreciable risk of permanent baldness.

Acne should be first treated by ultra-violet light from the tungsten arc ; if this treatment fails to effect a cure, as will probably be the case if the pustules are of long standing and are very indurated, then weak doses of X-rays should be applied filtered through ½ mm. of

aluminium. The previous application of ultra-violet radiation will materially assist the action of the X-rays, by bringing the skin to an increased state of radio-sensibility. One very great advantage of ultra-violet radiation in the treatment of acne, especially when the face is involved, is that the radiation imparts a very healthy appearance to the skin.

X-rays appear to be used in the treatment of acne in two degrees; in a mild form to exert a stimulating action on the skin, and in a more intensive form to destroy the skin glands. Great care should be exercised not to carry the latter form of treatment too far, otherwise a dried-up parchment-looking skin will result, which is almost more unattractive than the acne pustules themselves.

I have seen one case of this parchment skin in a young woman, occasioned by excessive X-ray dosage, much improved by the application of ultra-violet radiation.

Prurigo. The milder forms of this troublesome affection may often be relieved by the application of ultra-violet radiation; the more severe forms will require X-rays, and will not always be relieved by their use.

Chilblains, Angeio-neurotic Œdema, and Raynaud's Disease. Chilblains are best treated by the sinusoidal or galvanic currents. When the hands are affected, a pair of loosely fitting gloves should be made of Turkish towelling, and attached to the end of the finger and thumb partitions there should be a small pouch or bag into which the electrode is inserted. In this manner the lines of force of the current are correctly distributed over the affected area. If the galvanic current is employed, 10 to 15 ma. should be administered for forty minutes. When the sinusoidal current is administered its strength should be within the easy toleration of the patient, it should be administered for about thirty minutes, and it should not be of sufficient strength to excite contractions. Ultra-violet radiation,

administered in combination with either of these currents, materially assists in producing an early cure. The static breeze is indicated where there is much swelling or stiffness of the fingers. Chilblains of the feet may be treated by a modified form of glove, or by foot baths.

Angeio-neurotic œdema is usually appreciably benefited by the sinusoidal current; the œdema and stiffness can usually be to some extent reduced by the static breeze.

Raynaud's disease is generally much benefited by the stimulating action of the sinusoidal current combined with ultra-violet radiation and the static breeze.

Lupus may often be apparently cured by powerful and prolonged ultra-violet radiation. The tungsten arc should be employed with at least 15 amperes across the arc, and the radiation should be sufficient to produce an intense reaction, and preferably a blistering of the area treated. The treatment should be applied twice a week at first, afterwards once a week, and from time to time periods of rest should be given to prevent over-treatment, and in order to see the effect of the treatment after the erythema that it excites has subsided.

It has been urged that the Finsen lamp is superior to the mercury vapour lamp in the treatment of this condition, because the most effective part of the radiations is assumed to be in the more penetrating rays situated towards the violet end of the ultra-violet spectrum, a portion of the spectrum in which the mercury vapour lamp is comparatively deficient. This argument does not, however, apply to the tungsten arc lamp, for its radiation is very powerful in the region of the spectrum referred to; and there is no physical, clinical, or other reason why the tungsten arc lamp should not be equally effective as the Finsen lamp, provided that it is applied for a sufficient length of time and with sufficient intensity.

The radiation from the tungsten arc should be applied by means of a quartz condensing lens to small areas and

to lupus nodules; for the treatment of large areas the reflector should be employed.

A preliminary destruction of the larger lupus nodules by indirect diathermy, before the application of the radiation, materially aids the treatment.

Resistant cases should be treated by X-rays; the combination of the two radiations, X-rays and ultra-violet radiation, is often attended by the best results.

An important point must not be lost sight of. It has been asserted on high dermatological authority that, since the introduction of the treatment of lupus by X-rays, the percentage of cases that develop malignancy has much increased. If this is the case, the reason is obvious. Many cases of lupus recur again and again, and are more or less continuously treated over a period of twenty or thirty years. The basis of all the treatment is of a stimulating and irritating character. Can we be surprised, if irritation, as is generally admitted to be the case, stands in a most intimate causal relationship to cancer, that, when to the irritation of years of curetting and ointments the far more powerful irritation of repeated doses of soft X-rays is added, the growth suddenly flares up into a rapidly extending cancer?

X-rays and the gamma radiation of radium must be administered with extreme caution in old-standing cases of lupus.

Lupus is so prone to relapse, or to recur in other areas, that only an inexperienced or unduly optimistic operator will speak of permanent cures.

Warts, moles, epulides, capillary nævi, urethral caruncles, and similar growths are best treated by the indirect method of surgical diathermy.

In this treatment the patient lies on a condenser couch, consisting of one or more sheets of zinc or other metal covered and overlapped at each edge to the extent of an inch by a vulcanite sheet of about $\frac{1}{16}$ of an inch in thickness. He holds an electrode with both hands, the

metal plate of the condenser couch being connected with one terminal of the diathermy apparatus, and the hand electrode with the other terminal; a current strength, measured by a hot wire amperemeter of about 300 ma., is passed, and oscillates through the patient's body with very high frequency. The operator holds in his hand a suitable instrument, such as an aneurysm needle, or a primus pricker, with no wires of any kind attached to it, and applies its point to the part to be destroyed. The current with which the patient is charged inductively attracts a current of similar frequency from the capacity of the operator, and this oscillating current is concentrated on the part to be coagulated with such intensity that it is rapidly and almost painlessly destroyed. If the growth to be removed has a narrow pedicle, the heat is concentrated in its narrow stem, so that the portion to be removed drops away from its base. In dealing with such pedunculated growths it is best to hold them with a pair of artery or sinus forceps in place of applying the pricker.

The method is so free from pain, leaves no scarring, can be so accurately and delicately regulated, and its action can be so clearly watched throughout the application, that it forms an ideal method of removing these small growths.

In the treatment of corns I have not secured the same success as in the treatment of warts by this method. The mass of dry epithelium usually super-imposed on a corn does not readily conduct the current, and it is consequently apt to pass in a series of small disruptive sparks, which char the epidermis in a manner that should always, if possible, be avoided in the application of surgical diathermy, the object of this treatment being to coagulate and not incinerate the tissues. Dr. Howard Humphris has ingeniously devised a method of overcoming this difficulty by removing the dry epidermis by means of a steel burr previous to the application of the diathermy.

Hypertrichosis. The removal of superfluous hairs is

usually practised by destroying the hair follicle by electrolysis. The other methods are by X-rays and by diathermy.

Electrolysis is a troublesome, painful, and on the whole an unsatisfactory procedure, and more than 10 per cent. of the hairs so removed return. This is probably a form of treatment that is better performed by a 'beauty specialist' than by the ordinary electrotherapist.

X-rays are useful in some cases; the efficacy of this method is clearly seen in those cases of ringworm in which an overdose of the radiation has been followed by permanent baldness. Thick and really unsightly hairs often require a very large and dangerous dose of X-rays to secure their permanent removal. The downy and 'beautifying' hairs are the most readily removed by X-rays, and are consequently always absent after an efficient treatment; the skin therefore never recovers its former appearance, and many of the ladies who present themselves for this treatment should be advised to endure the presence of a slight moustache rather than incur the risk of worse troubles.

In the depilation of hairy moles, the hairs of which are very coarse and disfiguring, I have found diathermy the most efficient treatment.

Diathermy is a most powerful depilator; when treating port wine stains of the eyebrows I have been unpleasantly surprised at the ease with which the hairs of the eyebrow can be unintentionally removed.

For the depilation of coarse hideous hairs I employ indirect diathermy; a primus pricker is applied over the exit of the hair, a small diathermy current is turned on, and slight pressure is made on the pricker. In one or two seconds the pricker will be felt to slip through the skin, the depth of the hair follicle is then reached, and when a slight discoloration appears round the point of the pricker, the current is cut off and the instrument removed. This method will permanently epilate the

thickest hair, it will be followed by little or no scarring, and is less painful than electrolysis.

A photograph (Figs. 28 and 29) is given of an extensive

FIG. 28. Case of congenital hairy mole.

hairy mole of the face which is still under treatment by this method at the Radcliffe Infirmary. The patient is by no means cured yet, but has very greatly improved. I tried electrolysis in this case; the patient described it as a more painful method, and all the hairs removed in that way returned.

Hyperidrosis is best treated by lightly filtered X-rays. The technique presents no special features.

Boils, carbuncles, abscess, and ulcers. Ulcers and the

FIG. 29. The same patient during a prolonged course of treatment by indirect diathermy.

other conditions named, when their cavities have been thoroughly exposed by incision, are best treated by ultra-violet radiation. Wounds and varicose ulcers of the legs, when their surfaces are clean and free from crusts, do remarkably well with this treatment. Often

it is necessary to clean the ulcers by a preliminary zinc electrolysis.

The treatment of the cavities of boils and carbuncles by zinc electrolysis usually results in rapid improvement. Crops of boils may frequently be cut short by strong ultra-violet radiation.

The very acute pain that occasionally occurs in partially cicatrized varicose ulcers is best treated by the sinusoidal current. Ultra-violet radiation and X-rays are also useful in such a condition.

Scars and keloids are most effectually treated by radiotherapy. Occasionally considerable pain will be produced on movement as the result of dragging on muscular fibres which have become partially involved in scar tissue; the powerful contractions excited by the Morton wave current break down such adhesions and remove the pain. Such a condition was frequently met with in wounds of the back during the war. I have seen a deep sulcus transversely placed across the anterior surface of the thigh, due to scar involvement of the muscular fibres, entirely removed by the Morton wave current.

REFERENCE

Humphris, *Electrotherapeutics*, 1921.

CHAPTER IX

THE DISEASES OF THE ORGANS OF SPECIAL SENSE

The treatment of these organs, whether by electricity or other means, more properly belongs to the specialist within whose province they fall than to the general electrotherapist. It is far easier for the oculist, the laryngologist, and the aurist to learn the nature and application of the electrical remedies relating to their specialities than it is for the electrotherapist to acquire an accurate knowledge of the diseases of the eye, throat, and ear, and to become skilled in the use of the ophthalmoscope, the laryngoscope, and the ear speculum.

It would doubtless well repay such specialists, by visiting a well-equipped electrical department, to ascertain what electrical methods might be of service in their specialities.

Ultra-violet light and diathermy would probably be useful to the oculist. Surgical diathermy, both in the direct and in the indirect methods, has already proved of great service to the laryngologist. In diseases of the ear, the electrolytic action obtained from the application of galvanism with a solution of a zinc salt has already proved of the greatest value in the treatment of chronic otitis media, in the same way that a similar form of treatment has proved useful in the treatment of other suppurating cavities.

These remarks particularly apply to the application of electrical methods by means of, or in conjunction with, the use of special instruments, such as the application of surgical diathermy to intra-laryngeal growths, a form of treatment that necessitates the simultaneous use of the laryngoscope. The treatment of such conditions as suppurative otitis and ozæna by zinc electrolysis can be efficiently carried out in any well-organized electrical department.

CHAPTER X

ELECTRICITY AS A SURGICAL AGENT

LARGE malignant growths have been destroyed by, and satisfactory results have been recorded from, the employment of the caustic action of the products resulting from electrolysis. In these cases, chiefly carcinoma of the breast, zinc needles, coated with an amalgam of mercury, are plunged into the tissues to be destroyed. A bipolar method, in which two sets of needles are connected to the respective poles of the current supply, may be utilized; or a monopolar method may be used with an active and a large indifferent electrode. Dr. Massey, of Philadelphia, to whom we owe this method, has worked out its details in the most careful and exhaustive manner; he gives the following table of the 'Maximum currents safely applied by the Monopolar Method.

To the head, mouth, throat, and neck	300 to 400 ma.
To the left breast	Minor monopolar applications only.
To the right breast and thorax generally	400 to 800 ma.
Below the waist	800 to 1,600 ma.'

The tissues in the neighbourhood of the needles are destroyed by the caustic action of the nascent double salts of mercury and zinc formed as the result of electrolytic action.

Dr. Massey has published many records and photographs clearly illustrating the success that he has obtained by this treatment: but owing to the complicated technique and the danger associated with the employment of such high constant-current intensities, the method is not likely to come into general use.

The Surgical Uses of Diathermy

It is in minor surgery that surgical diathermy finds its most common application. It is capable of such delicate regulation that even the most superficial and the smallest of nævi can be removed by this method with the minimum of destruction and scarring. It is, on the other hand, so powerful that the most extensive surface growths can be removed by its use. Its direction is so certain and unvarying that the extent of the destruction can, by suitable technique, be confined to any required depth from the surface.

It should be distinctly understood that this method is one solely of tissue coagulation by heat: it is not a burning, a charring, or an incineration. The current should invariably pass in a conductive manner without the appearance of any sparks; whenever the current becomes disruptive and sparks begin to pass, burning of the tissues immediately commences, and then hæmorrhage may occur.

Burning and incineration of the tissues by heated irons and Paquelin cauteries have been rightly relegated to the surgical barbarities of the past, largely as the result of the danger of primary or secondary hæmorrhage that results from their employment. In the correct application of diathermy the tissues are 'properly cooked' or coagulated, and the vessels of the destroyed tissues are themselves coagulated.

The treatment may be applied by either a monopolar or a bipolar method. In the monopolar method a large indifferent electrode is applied at some convenient spot and connected with one of the terminals of the apparatus: a more convenient method is to employ a condenser couch in place of the indifferent electrode; no harm can then result from imperfect apposition, and no disturbance of the patient's clothing is involved. To the other terminal of the apparatus, an electrode terminating in a small metal

point is attached ; this point is applied to the tissue to be destroyed, and a current of from 200 to 500 ma. is switched on by means of a foot switch. A foot switch is absolutely necessary for the proper performance of the operation. The diathermic current, distributed over the large surface of the indifferent electrode, causes at most a mild sensation of warmth ; but, by means of the small metal point of the active electrode, it is concentrated or focused on the tissue with sufficient density rapidly to cause its coagulation.

The depth to which the coagulation takes place can be regulated by the intensity of the current and by the time during which it is applied.

A diathermy current of too high an intensity will rapidly char the superficial tissues, and will then lead to the passage of the disruptive sparks which it is so important to avoid. A current of weaker strength, applied for a longer time, will lead to a deeper coagulation with no burning or charring of the tissues. This is the result to be aimed at.

It has been alleged, and perhaps with reason, that diathermy applied in this manner is too blind a procedure to be applied to many regions and for the treatment of many superficial conditions : for there are no means of ascertaining either with certainty or exactitude the depth to which the coagulating process will extend ; and consequently important structures, such as subjacent nerves and ducts, may be unintentionally destroyed, or large vessels may be imperfectly coagulated, their walls laid open, and dangerous hæmorrhage set up.

These objections may be met by the employment of the bipolar method in cases where it is important definitely to limit the action of the current.

The bipolar method may be applied in two ways : either by the employment of two small button-like electrodes, of equal size—in this case a superficial line of coagulation of a width equal to the diameter of the

electrodes extends across the points of application. Or an active electrode, formed by eight to ten needles, secured to a small metal plate, may be inserted to the depth to which it is desired that the coagulation should extend.

I generally get such electrodes made by a tinsmith to suit the particular type of case which I am about to treat. In the treatment of the thickened and spreading circular edge of a large epithelioma of the skin, this type of active electrode is specially useful. The needles of the electrodes are inserted to the depth to which the coagulation should extend in the thickened edge of the growth, about an inch apart. The current is turned on, and when the intervening tissue has been destroyed the current is switched off and one of the electrodes is removed and inserted on the other side of the remaining electrode, and the process repeated, each electrode in turn being moved round, until the whole of the thickened edge has been destroyed. In this manner complete destruction, extending only to the required depth, is secured. In the treatment of such a growth as the one referred to, a large indifferent electrode is then applied, and a small active one run over the centre of the growth.

For the removal of such a structure as the tongue, a small flat spatula with a rounded blunt edge is lightly applied at the point at which it is desired to remove the tongue, and a current is applied of such a strength as slowly to coagulate the tissues. In this treatment the points to be avoided are undue pressure on the spatula and the occurrence of any charring.

The more severe operations of surgical diathermy are followed by considerable reaction in the surrounding tissues, the most marked feature of which is the œdema which is occasioned. This subsides in a few days, but may occasion serious inconvenience or even danger in such regions as the throat, and may call for a preliminary or subsequent tracheotomy.

Diathermy is an ideal method for dealing with certain intravesical growths. More skill, however, is required in the manipulation of the urethroscope than of the diathermy apparatus: its application therefore in such regions more properly belongs to the province of the urologist than to that of the electrotherapist.

The direction of the coagulating current in the application of surgical diathermy can be best ascertained by experimenting on a piece of raw liver, and Nagelschmidt rightly insists that such experiments should invariably be performed by an operator before he attempts to treat a patient by this method.

A very instructive experiment is to take a chunk of liver about 2 inches thick, and to apply to two opposite sides of it a circular electrode of about one inch in diameter; after passing a current of 1 or 2 amperes through such a piece of dead tissue for a few minutes, the circular mass of liver, intervening between the two electrodes, will be found to be uniformly cooked or coagulated. The diameter of the coagulated tissue will be found to be very slightly greater than the diameter of the electrodes, this slight difference being due to the conduction of heat from the heated tissues, and not to any diffusion of the current.

Another instructive experiment is to place a little raw egg albumen in a saucer, and to insert into it two needles, separated from one another by about 2 inches, respectively attached to the two terminals of the apparatus; a very weak current is gradually passed. The albumen will first commence to coagulate at a point in the centre, equally removed from the two needles, and will then gradually extend to the needles. This experiment shows that so far from the needles themselves becoming hot, and so heating the albumen by conduction, they, on the contrary, serve to dissipate some of the heat generated, so that the albumen in contact with them is the last to coagulate.

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